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NUCLEAR HELICOPTER AIR DENSITY INDICATING SYSTEM FLIGHT TEST PROGRAM

Donald W. Blincow

Tyco Laboratories, Incorporated

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This report describes the design, construction, and testing of the Nuclear Helicopter Air Density Indicating (NUHADI) system.

The NUHADI measures the scattering of X-rays, generated by an isotopic source, from the air volume outside the helicopter. The number of X-rays backscattered into the detector is proportional to the number of molecules per unit volume, i.e., the air density.

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The air scatter signal is compared to an internal signal, from the same source, during each cycle to provide a continuous self calibration.

The NUHADI was tested over the range of helicopter environments (temperature, humidity and vibration) and calibration/accuracy tested in the 41-foot NASA Langley altitude chamber to 20,000 feet. Flight tests were conducted at Fort Eustis, Virginia, on board a Bell UH-1H helicopter. The accuracy determined from the NASA Langley tests was ±0.75% (one sigma) or ±15μ slugs/ft^3.

EUSTIS DIRECTORATE POSITION STATEMENT

The Eustis Directorate has pursued several programs aimed at measuring the parameters which collectively determine rotary-wing lift, the ultimate objective being an on-board system that keeps the helicopter pilot continually apprised of his aircraft's lift margin.

The subject of this report is a device which measures air density by monitoring the degree of interaction between soft X-rays and air. An accurate measure of air density is attainable by averaging a sequence of the densitometer's digital readings, which are updated every 10 seconds. However, since these readings exhibit a standard deviation of the order of ±1% of sea level density, the device's real-time capability is rather limited.

The technical monitor for this contract was CPT Paul Luczka, Military Operations Technology Division.

DISCLAIMERS

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PREFACE

This report was prepared by General Nucleonics Division of Tyco Laboratories, Inc., under U.S. Army Contract No. DAAJ02-72-C-0015 (DA Task 1F162203A43405). The work was administered under the direction of the Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia. Technical representative for the program was Captain P. Luczka, USAAMRDL.

The program at General Nucleonics was performed under the direction of Mr. Donald Blincow. The author wishes to acknowledge the assistance of J. McCormick who designed the electronics.

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INTRODUCTION

The measurement of helicopter lift margin is a difficult and complex problem, and a variety of independent parameters must be accurately measured. One of the fundamental parameters needed is ambient air density. Lift is directly proportional to air density. If density is computed from air pressure and temperature, errors of several percent are possible with the best inputs.

The Nuclear Helicopter Air Density Indicating (NUHADI) system provides a direct measurement of ambient air density. An isotopic source, Krypton-85 gas in a uranium-lined capsule, generates X-rays in a continuous spectrum. These X-rays are emitted through the skin of the helicopter during a 5-second "source open" cycle, and the portions scattered back by air molecules are counted in the detector. A "source closed" cycle of approximately the same length follows, during which the detector looks directly at the source. The ratio of these two accumulated signals is scaled to provide a digital readout of air density in micro slugs/ft^3. Because the air density is measured with X-rays, which travel at the speed of light, the NUHADI is not affected by helicopter air speed, by rotor downwash, etc. Airborne dust or moisture has very little effect on the system's accuracy. Flight tests of the NUHADI system at Fort Eustis on a Bell UH-1H helicopter demonstrated the system's capability to measure air density to approximately ± 1% accuracy. Radiation dosimetry measurements and film badge readings from the people installing and flight testing the system showed the system to be quite safe.

NUHADI TECHNICAL DESCRIPTION

This section contains a detailed description of the NUHADI operation, subsystems and critical components.

PRINCIPLE OF OPERATION

The General Nucleonics nuclear helicopter air density indicator provides a direct measurement of the ambient air density outside the vehicle by means of backscattered X-rays. The X-rays are generated by an isotopic source of Krypton gas (Kr-85) which is in the rotating collimator shown in the functional diagram in Figure 1. When the collimator is rotated to the "open" position, X-rays are emitted out through the helicopter skin into the surrounding air. Part of these X-rays are scattered by the air molecules back into the detector. The number of X-rays scattered back each second (the count rate in the detector) is proportional to the number of air molecules per unit volume, the ambient air density.

For about 5 seconds of each 10-second cycle, the rotating collimator is in the closed or calibration position. The X-ray emission into the surrounding air is effectively shut off, but a hole in the rotating collimator is now aligned towards the detector. The detector count rate during this part of the cycle is compared with the count rate during the measurement cycle in the electronics/display subsystem. The ratio of open-to-closed count rate is scaled and displayed as air density in micro slugs/ft^3.

Figure 1 shows a block diagram of the detector electronics. The pulses from the detector, a photomultiplier tube with a sodium iodide crystal, are separated by the three level discriminators shown in the diagram. The lower two levels (#1 and #2) operate as a "window" discriminator; connected in an "anticoincidence" circuit, they allow only pulses exceeding the lower level but less than the upper level to be passed into the scaling circuits. A third level discriminator separates half the photo peak pulses from the Cs-137 source for gain control. These three levels are shown on the pulse height spectrum in the lower part of Figure 1.

NUHADI SYSTEM COMPONENTS

The NUHADI system is composed of three basic units: the sensor assembly, the electronics display unit, and the power supply unit. Figure 2 is a photograph of these three units.

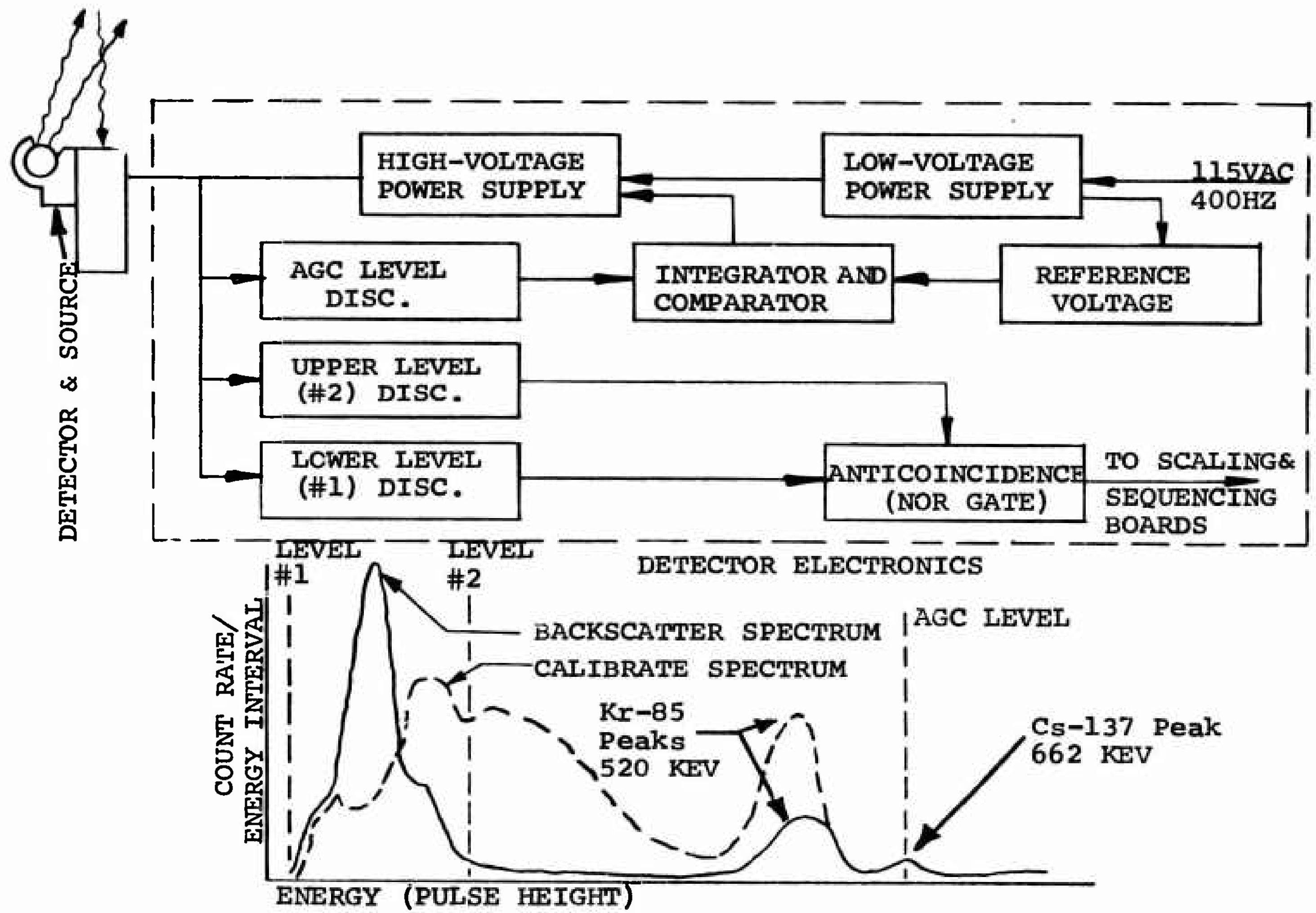

Figure 1. Detector Electronics Operation.

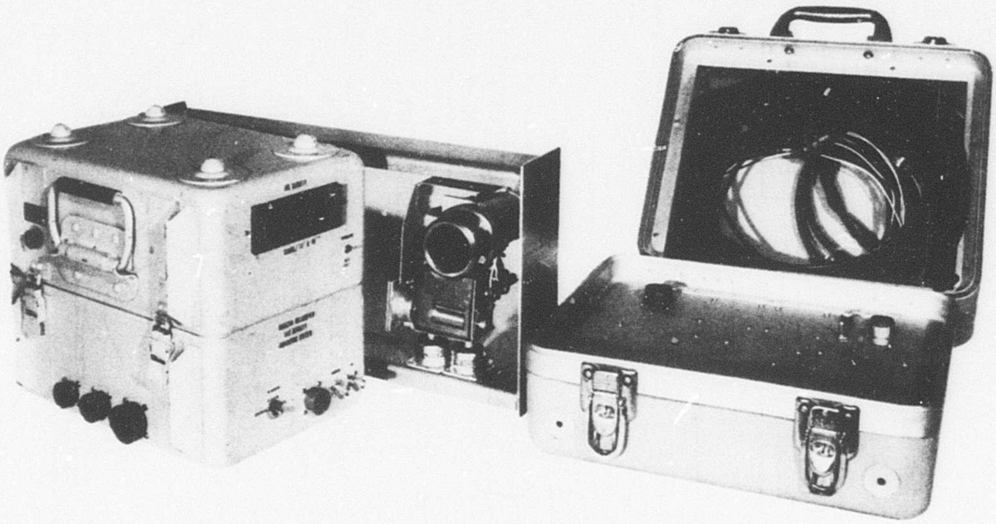

Figure 2. NUHADI System.

The electronics-display unit on the left contains all digital and sensor electronics. The display, showing air density in micro slugs/ft^3, is visible through a window on the side. The sensor assembly mounts on four vibration isolators in the mounting platform. The power supply unit, shown on the right, contains all the power converters in the lower half of its case. All its interconnecting cables are shown stowed in the upper half of the case.

DENSITY SENSOR SUBSYSTEM

The sensor subsystem consists of a radiation detector, which consists of a thalium activated sodium iodide (NaI) crystal and photomultiplier tube (PMT), an isotopic X-ray source (Krypton-85 gas sealed in a depleted uranium-lined capsule) in a rotating collimator, an automatic gain control (AGC) source (Cs-137) with the required shielding, and the collimators, the rotating solenoid, and mechanical mounting. Figure 3 is a photograph of the density sensor subsystem showing the essential components.

Isotopic X-Ray Source

The source used for the NUHADI density sensor is gaseous Krypton-85 (Kr-85). This source was chosen primarily for flight safety. Krypton is a noble gas which, like all noble gases, does not interact or combine with other elements. Even if inhaled or ingested, practically all of it will be expelled with no lingering effects on the body. In the event of a fire or crash which might rupture the source container, the krypton gas will be harmlessly dissipated in the atmosphere. The section entitled Radiation Safety and Handling Information of this report discusses radiation safety along with some background information on radiation.

The characteristics of Kr-85 are listed in the Table on page 7. The half life of Kr-85 is 10.76 years. This means that the number of Kr-85 atoms undergoing radioactive decay is proportional to the number of undecayed atoms present at that time; at the end of one half-life, only half the original number of atoms will be left. The rate of disintegration, and thus the detector count rate, will decrease exponentially following the decay constant λ (or the half-life $t_{1/2}$ where $\lambda = .693/t_{1/2}$.) Mathematically,

$$CR = CR_o \; e^{-\lambda t} = CR_o \; e^{-\frac{.693t}{t_{1/2}}}$$

where CR and CRo are the count rates at time t and at t_o (t=0) respectively and t is time since t_o.

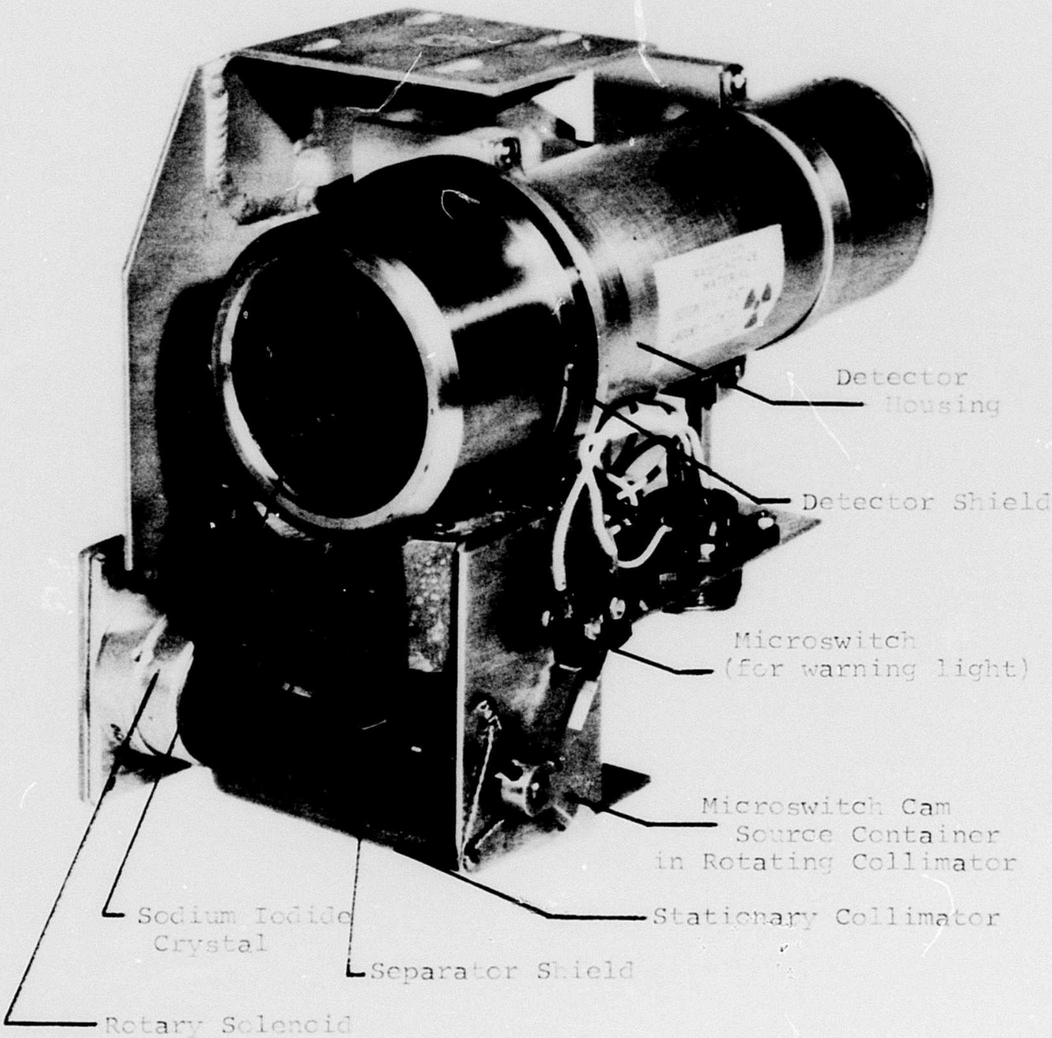

Figure 3. NUHADI Sensor.

TABLE

CHARACTERISTICS OF KRYPTON-85 (Kr-85)

Isotope	Kr-85
Physical Form	Inert Gas
Half-Life	10.76 years
Concentration	380 mc/ml

Emission	Energy		Abundance*
Alpha	-		None
Beta	E_{max} =	695 KeV	100%
Gamma		520 KeV	0.4%
X-rays (Bremsstrahlung) from beta rays	In Cu	40-80 KeV	~ 2%
	In Lead	50-100 KeV	~ 5%
	In U	60-120 KeV	~ 6%

NUHADI Source Encapsulation

.002 U liner in Copper capsule

*Abundance is used here to mean the percentage of emissions per disintegration of source atom. For the bremsstrahlung X-rays, the numbers given are the effective percentage emitted, i.e., the useful X-rays that emerge from the source capsule.

For most systems, the source half-life and required system accuracy together determine the maximum time between calibrations. For instance, in a Kr-85 system where ± 1% accuracy is required (and the count rate changes one-for-one with the parameter to be measured), the recalibration time is usually less than two months (since $e^{-\frac{.693t}{10.76\ yr}} = 0.99$ when t = 1.7 months). One great advantage of the NUHADI system is that source decay does not directly contribute to system error. Because the system compares the air density measurement and calibration measurement from the same source each cycle, the only error from source decay is the change in the ratio of background to Kr-85 pulses because the Cs-137 source decays more slowly (30-year half-life). This error accumulates quite slowly, however, as the total background is only about 10% of the signal and the "open" and "closed" count rates are approximately equal. Recalibration every two years will keep this error source to about 1/2%.

The NUHADI source is encapsulated in a copper source container with a .020-inch-thick wall, which has an inner liner of .002-inch-thick depleted uranium. The NUHADI system uses the bremsstrahlung X-rays created when the Kr-85 beta particles are stopped in the U foil. These X-rays are near the optimum energy to maximize air scatter. [1,2]

Detector

The NUHADI detector is a scintillation detection system which utilizes a sodium iodide crystal and a photomultiplier tube. The crystal emits a burst of light photons at about 4000A for each X-ray photon that is stopped in it. The photomultiplier tube (PMT) converts the light photons to electrical pulses and amplifies them by nearly a million times.

The NUHADI detector must operate from -40° to +70°C with better than 1/2% stability. While most scintillation systems operate over this temperature range, their output pulses vary as much as 40% with temperature.

General Nucleonics[3,4] developed an automatic gain control (AGC) system that uses a small source (0.5 microcurie of Cs-137) emitting a gamma higher in energy than anything from Kr-85. The AGC keeps the electrical pulses from this referance source at constant amplititude and thus stabilizes the detector gain. Figure 1 shows the operation of the detector electronics in utilizing the AGC source spectrum, and a pulse height spectrum diagram in the lower left-hand corner shows the location of the discriminator levels relative

to the various photon energy peaks.

The 662 KeV gamma from Cs-137 is easily resolved above the 520 KeV Kr-85 gamma. The AGC discriminator is set at the peak of the 662 KeV gamma spectrum so that $\sim$ 200 counts/sec of the 400 counts/sec Cs-137 photopeak are integrated into the AGC channel. The DC voltage from the integrator is compared to a constant DC supply voltage, and the difference controls the high voltage to the PMT. If the detector gain should decrease (from temperature effects in the crystal, PMT or from other causes), the integrator will receive less than 200 counts/sec from the AGC discriminator level and will automatically increase the voltage to the PMT. The opposite will occur if system gain should increase. Because only 200 counts/sec are used in the AGC channel (to avoid interference in the data channels), the AGC integrator needs a long time constant. A 180-second RC integrator is used which gives 1 σ statistics (AGC counts) of $\pm$ 0.4%. Setting the AGC level on the peak of the Cs-137 gamma gives a relative slope, AGC count rate/data count rate of $\sim$ 2/1. Thus, the gain stability is $\sim \pm$ 0.2% for the data channel.

The detector used is a 2-inch-diameter by 1/2-inch-thick thalium activated sodium iodide scintillator (Harshaw 802 NaI crystal) optically coupled to an EMI 9656 photomultiplier tube on Figure 7. These are standard laboratory components offering good pulse resolution, medium-high count rate capability and low noise over the required temperature range. The magnetic shielding (used around the PMT) is a double wrapping of foil, .004-inch Conetic foil next to the tube (shielding from low flux magnetic fields) and .004-inch Netic foil on the outside (shielding from high flux fields). The inner foil is also used as a static charge shield for the cathode - it is held at cathode potential to prevent cathode "poisoning" from large potential differences across the glass tube wall.

The experimental pulse height spectrums for the window-open and window-closed positions are shown in Figures 4 and 5. Both of these spectrums resulted from the same Kr-85 source with a uranium liner. The approximate discriminator levels are shown in these figures (also shown in Figure 1). The counts between level 1 and level 2, the anticoincidence window, are in the data channels. Figure 6 is a spectrum taken with the window open, but with a lead shield over the front of the detector. The counts in the data window in this spectrum are from leakage, Cs-137 Compton events and background counts.

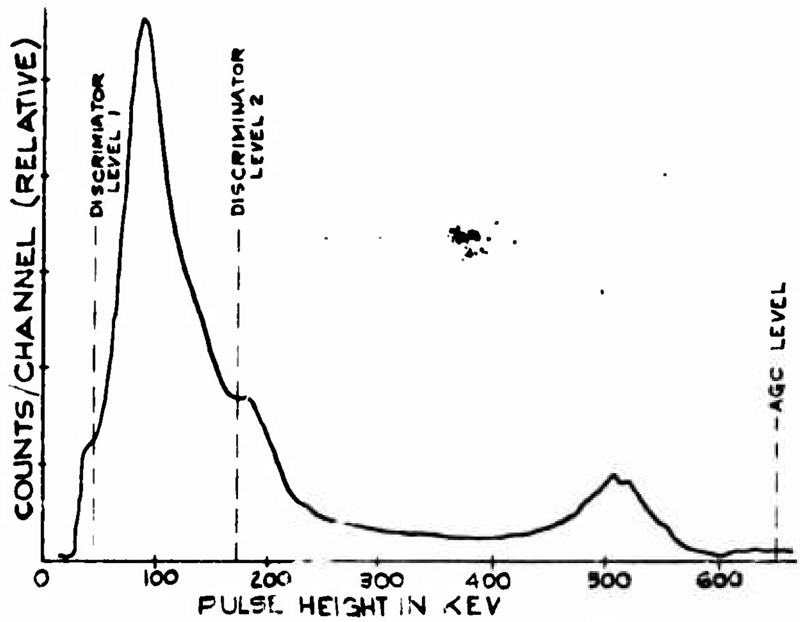

Figure 4. NUHADI Spectrum With Collimator Open.

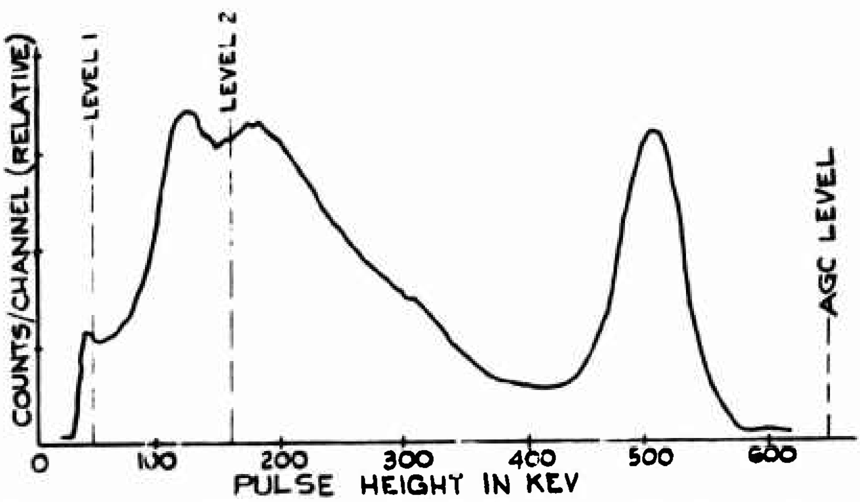

Figure 5. NUHADI Spectrum With Collimator Closed.

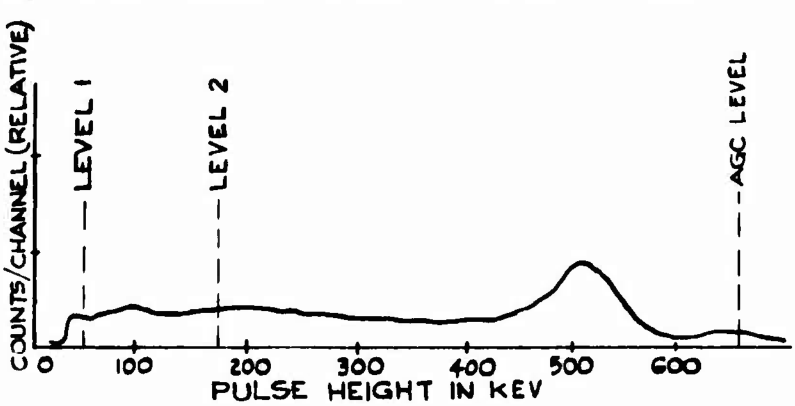

Figure 6. NUHADI Spectrum With Collimator Open and 1/8-Inch-Thick Absorber Over Detector.

Rotating and Stationary Shields

The NUHADI sensor uses three basic shields or collimators. A short cylindrical shield around the crystal reduces background (from cosmic rays and earth gammas) and attenuates direct transmission from the NUHADI source. The stationary source collimator is open to the front (towards the air outside the helicopter) but shields the source in all other directions. The rotating collimator, also open on one side, is a cylindrical shield which contains the source. This collimator rotates between two positions 90° apart. In the "open" position, it combines with the stationary collimator to allow a broad beam of X-rays to emerge from the helicopter. In the "closed" position, this emergent flux is cut off, but now a hole in the side lines up with a hole in the stationary collimator and detector shield to allow a beam of X-rays to go directly into the crystal. All three of these shields, shown in Figures 3 and 7, are made of kulite, a tungsten alloy. The stationary shielding is increased by a block of lead between the stationary kulite collimator and the detector shield. The rotating collimator is controlled by a rotory solenoid (Cliftronics R1441R09030) also shown in Figure 7. This solenoid uses 15-volt DC from the NUHADI power supply ($\sim$ 1 amp) to rotate and hold the rotating collimator open. This collimator is closed and held closed whenever the solenoid is not energized by a coiled spring in the front of the solenoid. The shaft of the rotating collimator extends through the stationary shield and a cam attached there engages a microswitch when this collimator is in the "closed" position. The normally closed microswitch, a Cherry E61, turns the warning light off when the solenoid is completely closed.

Warning Light

The warning light mounts on the outside of the helicopter, near the front of the sensor where the maximum radiation flux emerges from the tail boom, and is illuminated whenever the source rotating shutter is opened. The light, a Dialco light with an amber lens, is visible up to 25 feet in any direction in the hemisphere defined by the side of the fuselage, i.e., the port side of the tail boom. When the light is on, the source shutter is open and radiation levels are up to 16 mR/hr (see section entitled Radiation Safety and Handling Information for discussion of radiation exposure, dose rate, etc.) at 2 feet from the surface. When the light is off, the shutter is closed and the radiation level is reduced to 2 mR/hr or less at 2.5 feet.

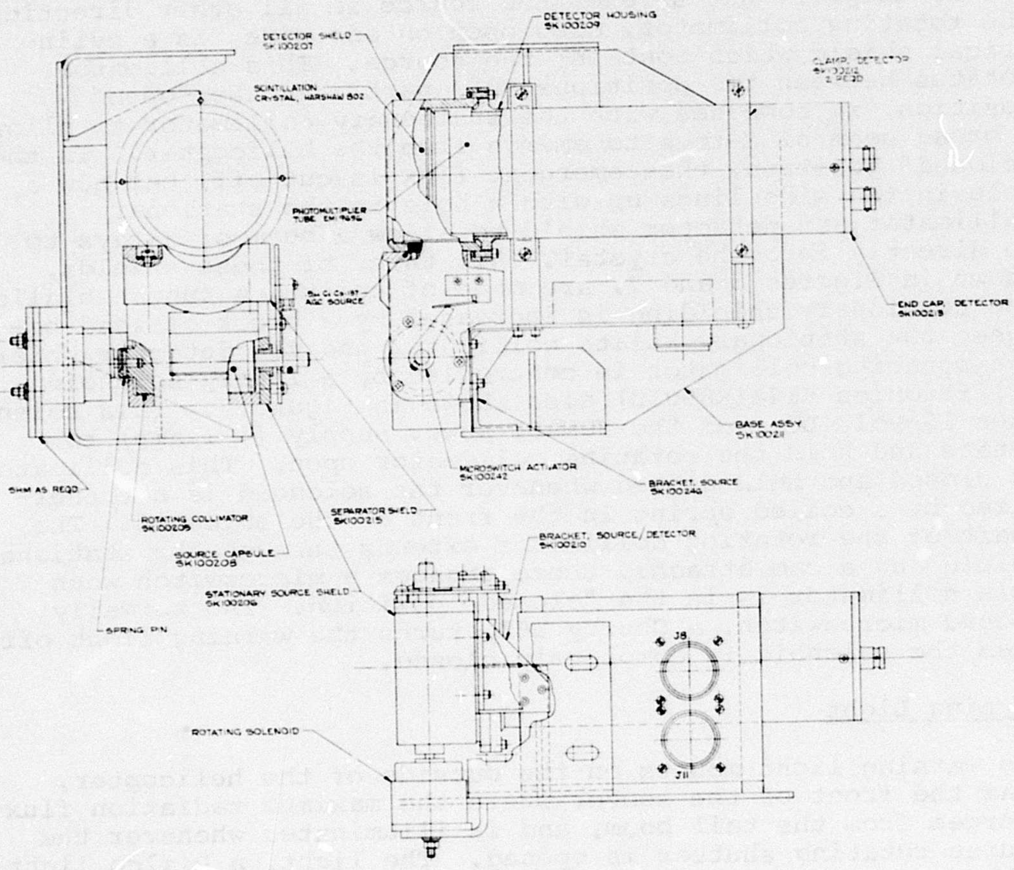

Figure 7. NUHADI Sensor Assembly.

ELECTRONIC/DISPLAY SUBSYSTEM

This assembly contains all of the logic and control circuitry necessary to sychronize the electromechanical operation of the sensor, and to accumulate, scale and display data from the sensor.

Two control toggle switches are mounted on the case. The OPERATE, BIT switch allows a quick check of the data processing electronics when set to BIT (built in test position). In this position, the readout should indicate approximately 1000. The WINDOW-OPERATE, CLOSED, OPEN toggle switch controls the switching mode of the sensor shutter. It can be held continuously in either of its extremes or be allowed to cycle normally when set to OPERATE. The data processor electronics are not affected by the position of this switch.

The electronic subsystem employs digital techniques to the maximum extent possible in performing the required data processing and information display for the NUHADI system. The photomultiplier tube (PMT) signal output is immediately transformed to a voltage level consistent with the data processing logic to facilitate the digital design concept. Only in the AGC high-voltage control circuitry is the analog domain employed in the system.

The following detailed discussion deals with the operation of the electronic subsystem, from the PMT signal input to the final output display.

Detector Electronics

The detector electronics are shown in Figure 8 in a simplified block diagram form. The signal from the PMT is coupled through buffering emitter followers to the non-inverting inputs of three high-speed, integrated circuit, pulse height comparators (μA710). The inverting input of each of these comparators is connected to a potentiometer, which allows a negative bias voltage to be adjusted, independently, for each comparator. The operation of these comparators is such that when the amplitude of the input signal pulse from the PMT exceeds the preset bias level by 5 millivolts, the comparator output will switch from its normally high level of +3 volts to a logic 0 level of 0 volts. Thus, the input analog signal is converted to three standardized digital pulses, each of which is generated at a different amplitude on the input voltage waveshape. Two of the comparator outputs are logically combined to form the "window" pulse output, and the third provides the AGC pulse output. The window pulse is sent directly to the data processing logic. The AGC pulse is inputted to a rate meter integrator circuit which converts the pulse rate to a DC voltage. The

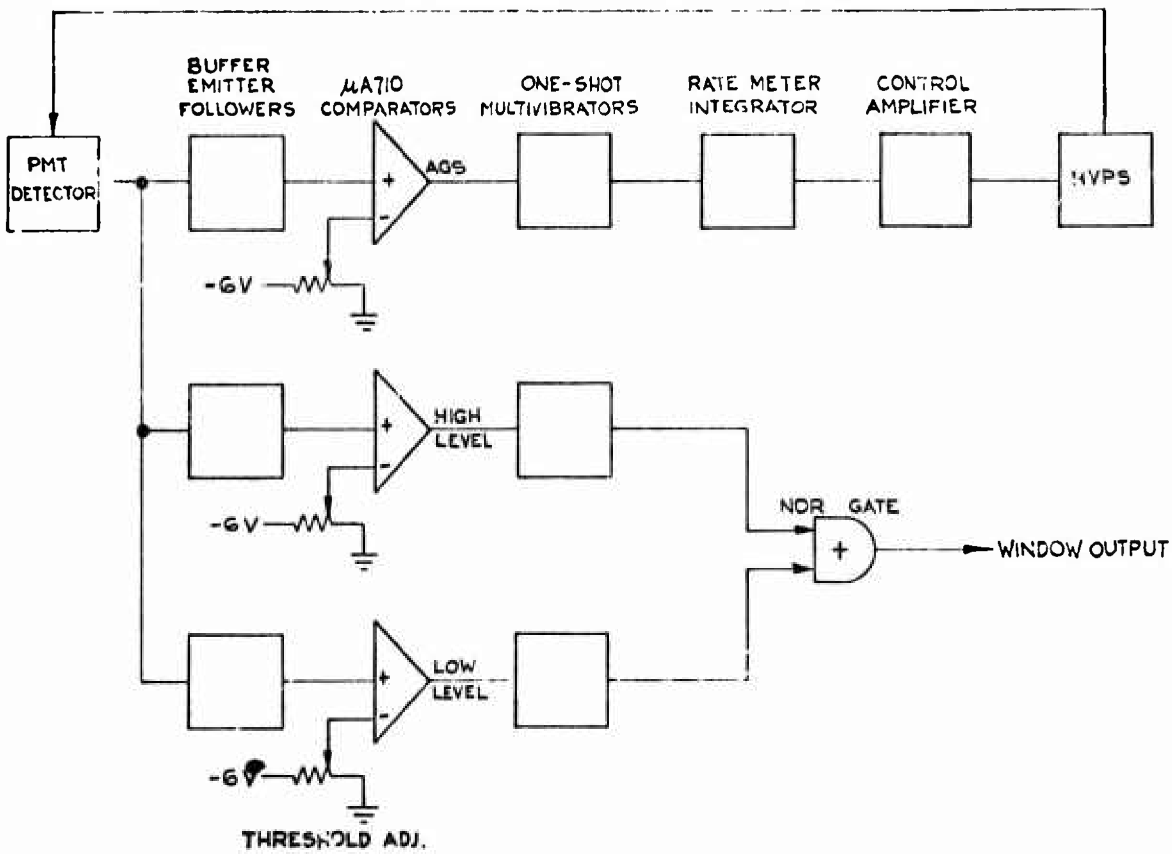

Figure 8. Detector Electronics.

AGC pulse discriminator is set to trigger at an amplitude of approximately - 1.4 volts. This amplitude represents the pulse spectrum obtained from the Cs-137 AGC source. The PMT pulses from the Kr-85 source, which are considerably lower in amplitude, do not trip the AGC comparator, and thus do not affect the AGC control circuitry. The count rate from the AGC comparator is approximately 200 pulses per second (PPS). In order to reduce the effects of statistical variations, a very long RC time constant (180 seconds) is employed in the rate meter integrator. The rate meter DC output voltage is then amplified by a differential amplifier state and used to control a series pass transistor. This transistor supplies the low-voltage input (+12V maximum) to the high-voltage inverter. As the input +12V is varied, the high-voltage output will change proportionately. In this manner, the AGC count rate is used to control the high voltage to the PMT, which in turn varies the PMT signal pulse amplitude and, therefore, the pulse rate which will exceed the AGC comparator threshold level.

The window pulse output is generated in the following manner. One of the comparators is biased to trip at a relatively low level on the input pulse - at about 95 mv. In order to reject unwanted pulse spectrums, a high limit on the input pulse is also established. The high level comparator is biased at this voltage - between 500 and 600 mv. When the input pulse is within these two desired limits, the low-level comparator will be on and the high-level comparator will be off. Expressed logically, this is $a\bar{b}$. The logic equation is implemented by a Nor gate connected to the "a" and "b" outputs. In order to avoid minute time alignment problems (the high-level comparator will trip at some time later than the low-level comparator on any input pulse, due to the finite rise time of the pulse), the "a" output (low) is delayed 3.5μ second before being combined with the "b" output in the Nor gate. Both the high and low comparator outputs are "squared up" by one shot multivibrations before being sent to the Nor gate. The Nor-gate output is then sent to the data processing logic for counting.

Data Processing Electronics

General

The data processing electronics are illustrated in Figure 9 in block diagram form. Basically, the subsystem operates to control the accumulation and readout of counts in a binary counter - the "A" scaler in Figure 9. The operation of the "A" scaler, in turn, controls the counting time of the "B" scaler, which is used to generate the display information. The TB_{tc} (Time Base temperature

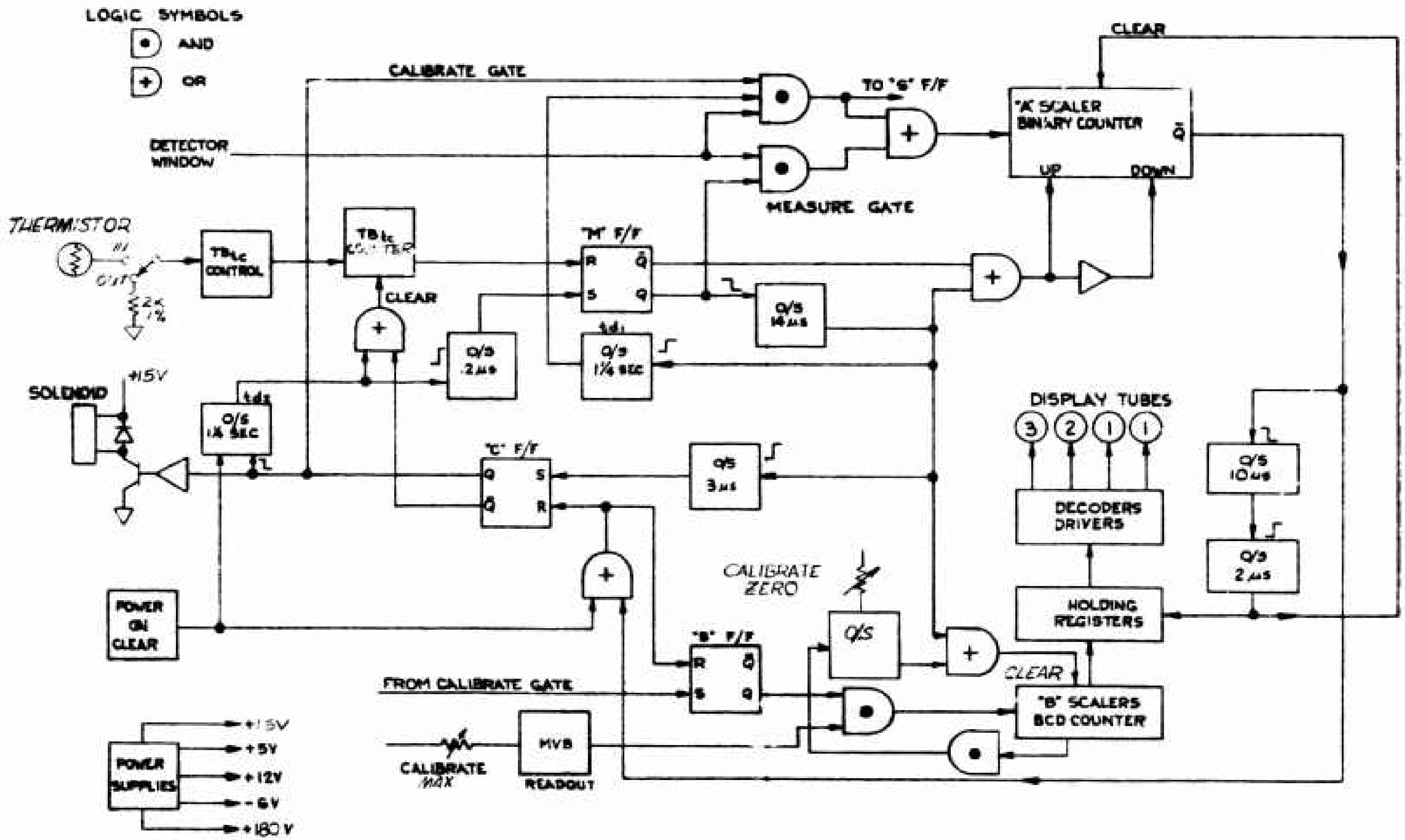

Figure 9. Data Processing Electronics.

control) counter, and associated logic circuitry, generates the time base gate. The data processing logic controls one other system operation, that of opening and closing the Kr-85 source window mechanism by activating the electromagnetic solenoid.

The data processing electronics are constructed almost entirely by using integrated circuit modules. The logic line employed is positive 5V, TTL, series SN7400N.

Time Base Temperature Control

This control circuit establishes the time period for the measure cycle. The circuitry is shown in detail in Figure 10. The more critical components are housed in a temperature controlled oven, shown in dashed lines in the figure. The control circuit consists of an operational amplifier with a multivibrator network in its feedback loop. The operation of the circuit is such that an input change at the noninverting terminal of the operational amplifier produces a like change at the inverting terminal, by altering the frequency of the multivibrator. The frequency of the multivibrator is then counted down by 20,000, through four decade counters and one binary counter, to produce the measure gate input signal for the data processor. The signal generated actually terminates the measure gate by resetting the "M" flip-flop in the data logic.

A toggle switch labeled TEMP SEN IN-OUT selects whether the time base is actively controlled by a temperature sensing thermistor (not supplied with NUHADI) or not. Then the switch is set to OUT, a precision 2K resistor replaces the thermistor, and no exterior temperature is employed. The switch is located inside the electronics display case.

Data Logic

The operation of the data logic is described briefly in the following paragraphs. Basically, the operation sequence involves controlling three flip-flops - "M" (measure), "C" (calibrate), and "S" (readout scaler). There are only two adjustments in the logic: one varies the readout multivibrator frequency, so that the maximum density indication may be set, and the other adjusts a one-shot period used to calibrate density near zero. Figures 9 and 11 (which show the major timing signals) should be referred to during the following discussion of the operation sequence.

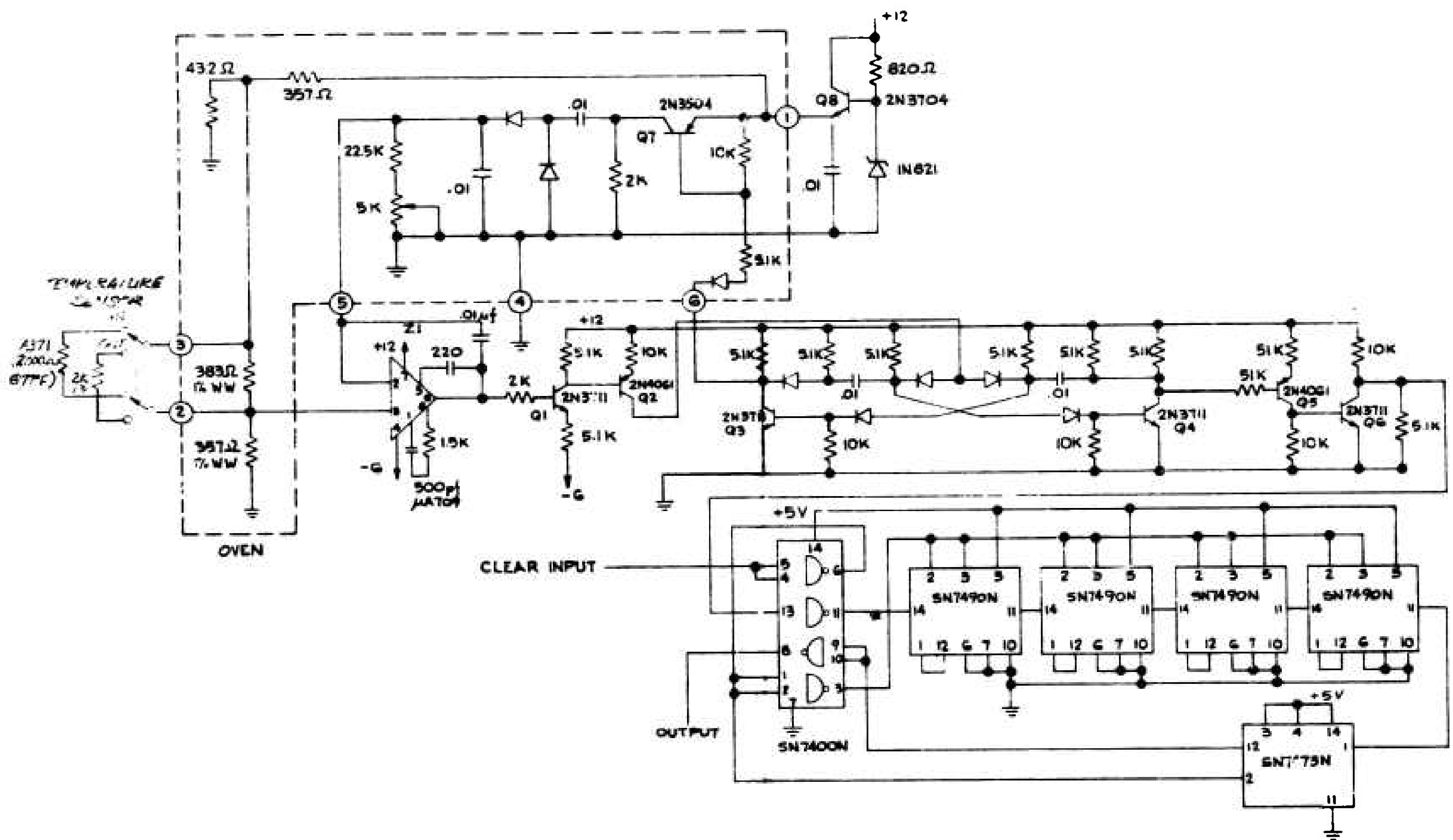

Figure 10. Time Base - Temperature Control Counter.

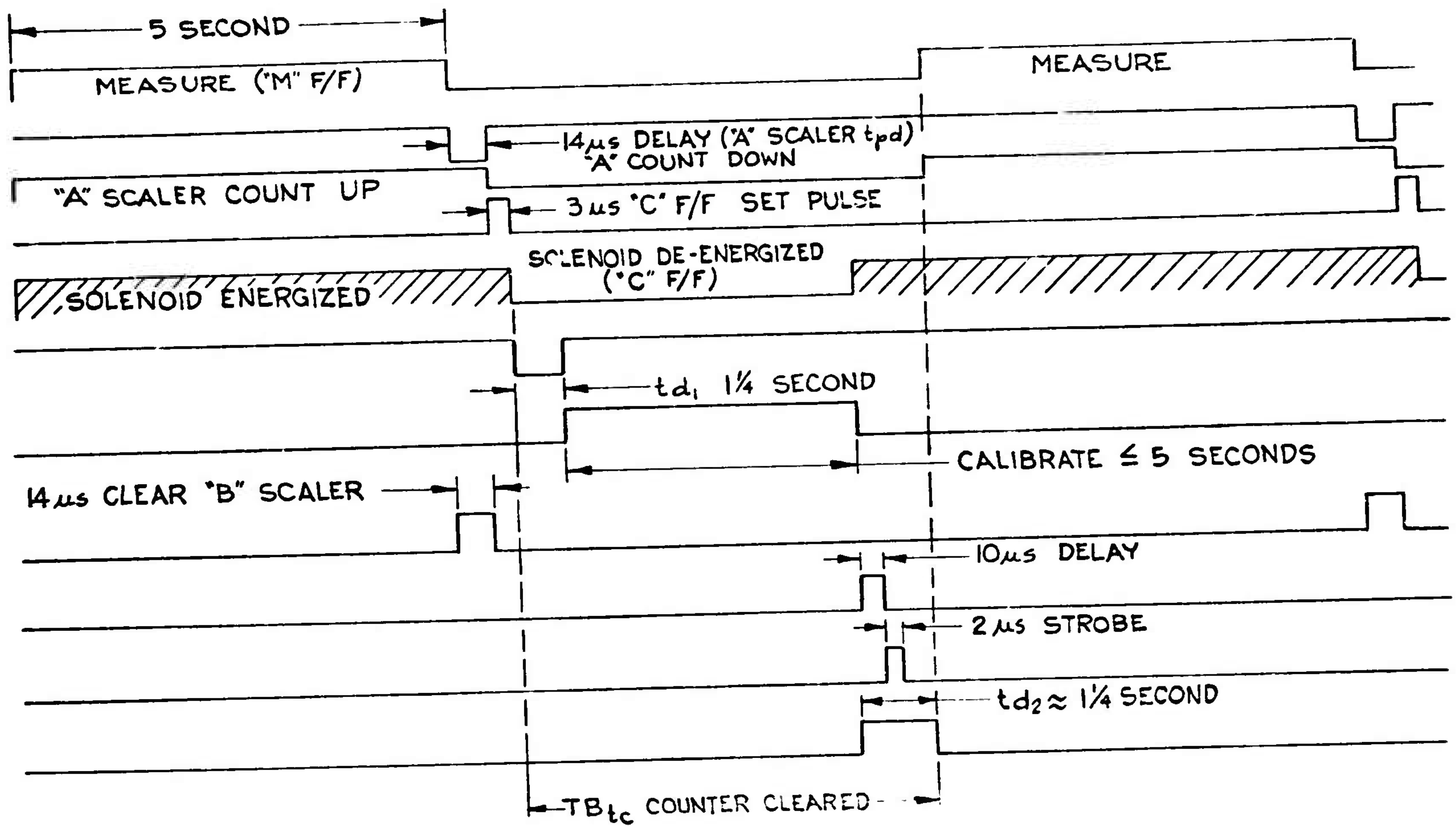

Figure 11. NUHADI Timing Diagram (Logic).

Starting Conditions

Application of +5 VDC energizes Power On Clear Circuit which resets "C" and "S" F/F's and triggers td_2 O/S. The O/S pulse clears the TB_{tc} counter, and the trailing edge also sets the "M" F/F. This initiates the measure cycle. The solenoid is activated.

Measurement Cycle

1. "A" scaler accumulates counts in the normal "count up" mode.

2. The TB_{tc} counter accumulates counts to preset quantity "N".

3. When the TB_{tc} counter reaches "N", the "M" F/F is reset, which stops input data to the "A" counter and initiates the following sequence:

   (a) The 14μs O/S is triggered and clears the "B" scaler (5 SN7490N's) F/F's

   (b) The trailing edge of the 14μs O/S triggers the 3μs O/S, which sets the "C" F/F to initiate the calibration cycle

   (c) The countdown gate is applied to the "A" counter. The gate is "or'ed" with the 14μs one shot to allow for transition time in the counter.

Calibration Cycle

1. The "C" F/F setting initiates the following:

   (a) The TB_{tc} counter is held clear

   (b) The calibrate gate is logic "1"

   (c) The solenoid is de-energized

   (d) The td_1 O/S (1.25 sec) is triggered and inhibits input data to the "A" counter for the 1.25-second period (equal to, or greater than, the delay time of the solenoid)

2. At the end of the td_1 O/S period, input data (calibration data) enters the calibration gate and subsequently the "A" counter.

3. The first pulse to enter sets the "S" F/F, and the scaler multivibrator output is allowed to enter the "B" scaler.

4. The "B" scaler is allowed to count until the "A" counter MSB* is set (Q flips to logic "0").

5. The "A" counter Q transition initiates the following:

   (a) The "C" F/F is reset, which:

      (1) activates the solenoid

      (2) triggers the td_2 O/S, which holds the TB_{tc} counter cleared for an additional 1.25 sec (equal to, or greater than, the delay of the solenoid).

   (b) The "S" F/F is reset, which stops the multivibrator signal from entering the "B" scaler.

   (c) The $10\mu s$ O/S is triggered (compensating for the "B" scaler transition delay).

   (d) The trailing edge of the $10\mu s$ O/S triggers the $2\mu s$ O/S generating the strobe pulse and the "A" counter clear pulse.

   (e) The strobe transfers the "B" scaler data to the holding register (SN7475N's), and this count is displayed on the nixie indicators.

   (f) The "A" counter clear pulse resets all registers in the "A" counter.

6. The trailing edge of the td_2 O/S causes the "M" F/F to be set, energizes the measurement gate and allows the measure cycle to repeat.

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*Most significant bit

Electrical Display

The electrical configuration of the display system is shown as part of Figure 9. It consists of the readout multivibrator, "S" flip-flop, a five decade BCD counter, a 16 bit holding register, the indicator decoder-drivers, the display indicators, and the associated timing signal inputs.

Operation of the display system is straightforward and conventional and may be briefly described as follows. The "S" flip-flop will be set when the data processor starts the calibrate cycle of operation. This enables the readout multivibrator signal to pass through the control Nand gate and enter the BCD counter. The counter will then accumulate counts for the period that the "S" flip-flop is set, the total counts being determined by the readout multivibrator frequency. When the "A" scaler overflows in the countdown mode, the "S" flip-flop will be reset. The "B" scaler contents are then gated to the holding register by the strobe timing signal. After this transfer has taken place, the BCD counter is returned to zero by the clear pulse, so that it is ready for the next calibrate cycle. The holding registers, and therefore the display, are updated at each strobe input. The BCD "B" scaler is designed to handle the maximum input counts without overflow and is capable of holding 10^5-1 counts. The holding register and display disregard the least significant decade of the "B" scaler, only four decimal digits are displayed, since four digits provide a resolution capability of .01%. This is well within the accuracy requirements for the system.

There is one other aspect of the display system that should be mentioned. This is the offset required to make up for the counts received other than air backscatter (gammas penetrating the shields, cosmic rays, etc.). If the indicators were allowed to display the readout multivibrator counts accumulated during this condition, the readout would naturally be erroneous. This error count is a constant value and so may be subtracted from the "B" scaler contents before display. The subtraction is implemented in this manner. The "B" scaler output is monitored and when the count reaches 30,000, a signal pulse is generated. This pulse, in turn, fires a one-shot multivibrator, which resets the "B" scaler to zero. The reset action is allowed to take place only once during a calibrate cycle so that the count may progress beyond 30,000. This is accomplished by using a RESET flip-flop, which will produce only one output transition regardless of the number of times it is set. The RS flip-flop is reset after each calibrate cycle is completed. The period of the "B" scaler reset one-shot is made variable so that a continuous adjustment is available for calibration.

POWER SUPPLY SUBSYSTEM

The DC voltages required to energize the electronics/display and the density sensor are derived from five separate power supply modules housed in the power supply assembly. The output voltages and currents from these supplies are as follows:

+ 5V @ 3A
+ 12V @ 0.2A
+ 15V @ 1.2A
+ 195V @ 0.02A
- 6V @ 0.35A

All of the supply modules require 115VAC, 50 to 440 Hz input power. The input current drain is 200 ma for the power supply. Figure 12 is a schematic of the NUHADI power supply subsystem.

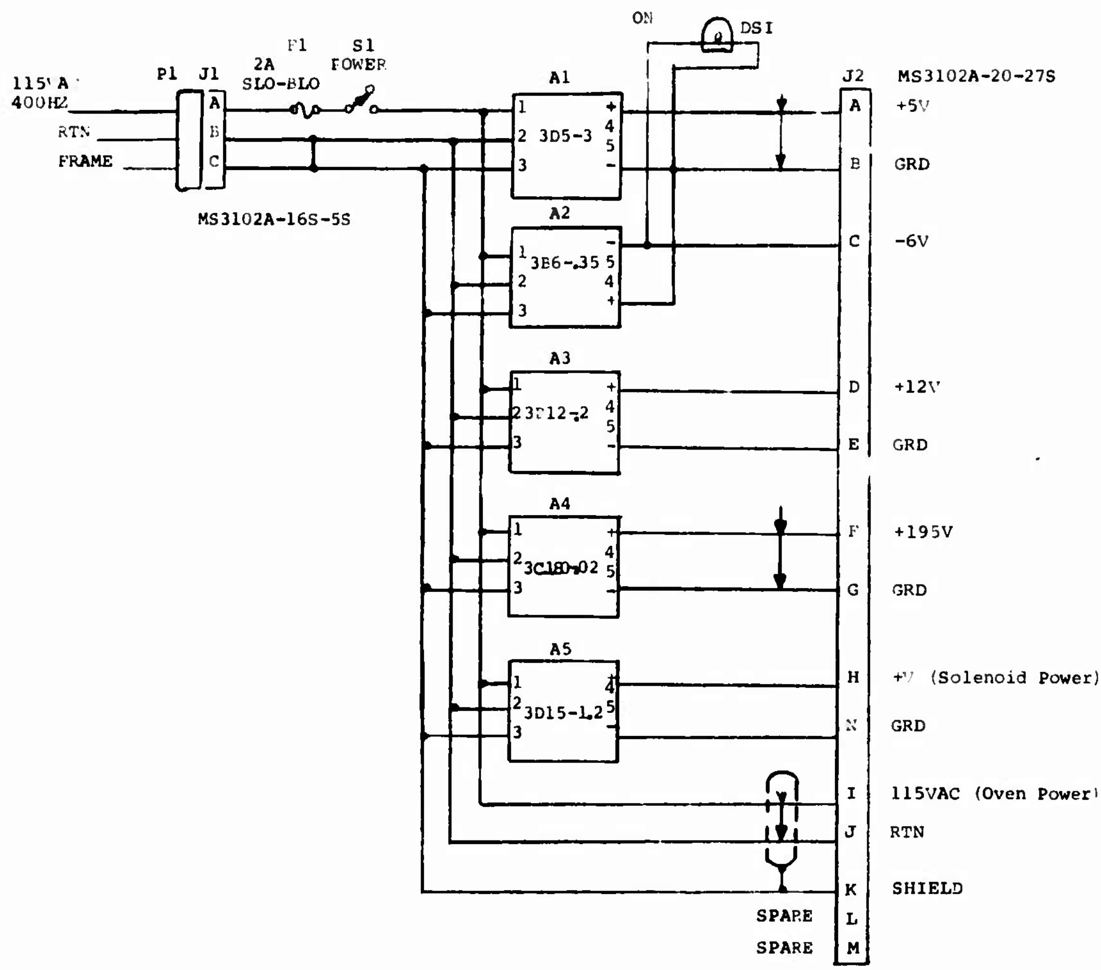

Figure 12. NUHADI Power Supply.

NUHADI TESTS

The NUHADI was environmentally tested at GND for sensitivity to the temperature, humidity, and vibration environment that it would be exposed to in use.

A calibration/accuracy test was then performed in the NASA 41-foot-diameter altitude chamber at Langley AFB, Virginia. Finally, the NUHADI was installed and flight tested on a Bell UH-1H Helicopter at the Eustis Directorate. These tests and the test results are discussed in the following sections.

ENVIRONMENTAL TESTS

To assure that the operation of the NUHADI would not be adversely affected by the helicopter flight environment, the system was exposed to the following environmental parameters at GND.

Temperature Environment	-65° to + 160°F
Humidity Environment	25% to 100% RH at 110°F
Vibration Environment	MIL-STD-810B

These tests were made with the source collimator and detector partially shielded so that the open-cycle count rate would represent a constant density air volume - unaffected by changes in the actual air density around the sensor or by material near it. Thus, the effects of the particular environment (temperature, humidity or vibration) were isolated from exterior effects on the NUHADI readout. Also, this allowed testing in small chambers where the sensor normally requires a free air volume in front of it at least 10 feet in diameter.

Temperature Tests

The NUHADI sensor was tested over the temperature range while readings were taken of the readout and the open and closed count rates. The readout was found to increase 0.22% in the respect to ambient at the maximum cold temperature and to decrease 0.48% with respect to ambient at the maximum high temperature.

HUMIDITY TESTS

The NUHADI sensor was operated in the temperature chamber at 110°F at less than 25% relative humidity for 1/2 hour. The humidity was increased to the saturation point and held for 1/2 hour while data was recorded. The NUHADI readout was stable

to within ± 0.5% during this test.

Vibration Test

The NUHADI sensor was exposed to the vibration environment specified for helicopter instrumentation in MIL-STD-810B while operating. This environment consists of:

5 to 20 CPS 20 to 34 CPS	—	0.10 in. Double Amplitude ± 2G Peak Acceleration
34 to 54 CPS 54 to 500 CPS	—	0.036in. Double Amplitude ± 5G Peak Acceleration

When the sensor was vibration tested without vibration mounts, it was found to have several resonance points.

	Acceleration Levels: ± g (peak)	
Frequency in Hz	Excitation	Resonance
30	2	*
74	5	12
105	5	8
160	5	35
320	5	35

During resonance dwell at 160 Hz, the screws in the rotating collimator end plate loosened causing the collimator to stick closed. The unit was disassembled and LOCTITE was applied to the threads. At 320 Hz resonance dwell, the screws in the stationary shield end plate loosened; these were safety wired. No further problem with loosening screws was found.

The readout was affected at the resonance frequencies, especially at the low frequency when the rotating collimator chattered. The sensor was then mounted on vibration isolators, which are specifically designed for the low-frequency vibration encountered in helicopters (Barry H44-BA-4).

These isolators reduced the two lower frequency resonances by a factor of 2 or more and the upper two resonances (160 and 320 Hz) by factors of more than 100. They effectively eliminated resonance points and provided smooth operation throughout the frequency range.

---

*The rotating solenoid began to chatter, and the warning light blinked on-off.

CALIBRATION/ACCURACY TEST

The NUHADI system was tested for accuracy and to provide calibration data in the NASA 41-foot-diameter altitude chamber at Langley AFB, Virginia on October 5, 1972.

Calibration

In this test, both collimator open and collimator closed count rates were recorded, along with the NUHADI readout. This allows construction of a calibration plot: count rate ratio (CR open/CR closed) vs air density. Ten readings were recorded at each 4,000-foot interval (chamber pressure altitude) from 0 to 20,000 feet and back to sea level. Figure 13 shows count rate ratio plotted against both air density (calculated from chamber pressure and temperature readings) and NUHADI readout. With an exact calibration, these two lines would completely overlap. Figure 14 shows the NUHADI readout plotted against calculated chamber density. Bringing this line to coincide with the "desired calibration" also shown on this plot is equivalent to making the two lines in Figure 13 overlap. Calibration using the count rate ratio allows the NUHADI to be calibrated in the lab, because the count rates are independent of calibration.

Several calibrator plates were placed over the sensor while it was mounted in the chamber, and count rates and readout data were recorded. These data points are noted on Figure 13. It was found that the 1/8 inch lead absorber was too thick to be used for a calibration plate, as it would give a negative readout. This was evident because it absorbed practically all air scattered photons while causing a slight increase in collimator-closed count rate.

An absorber shield of .040 inch cadmium over the detector was found to be the best calibration plate. This gave a positive readout high enough to facilitate calibration but still corresponding to a very low air density (see Figure 13).

Accuracy

The humidity indicator furnished by NASA-Langley did not function reliably, so humidity changes were ignored in calculating chamber air density. This was not considered too critical, as the mixing ratio (the ratio of water molecules to air molecules) should have remained relatively constant. Although the accuracy of the calculated chamber air density could not be exactly determined without a humidity measurement, it was estimated to be approximately $\pm$ 0.5%. When the NUHADI readout was plotted against calculated air density (Figure 14) all the data points fall within $\pm$ 0.7% of the best straight line fit to

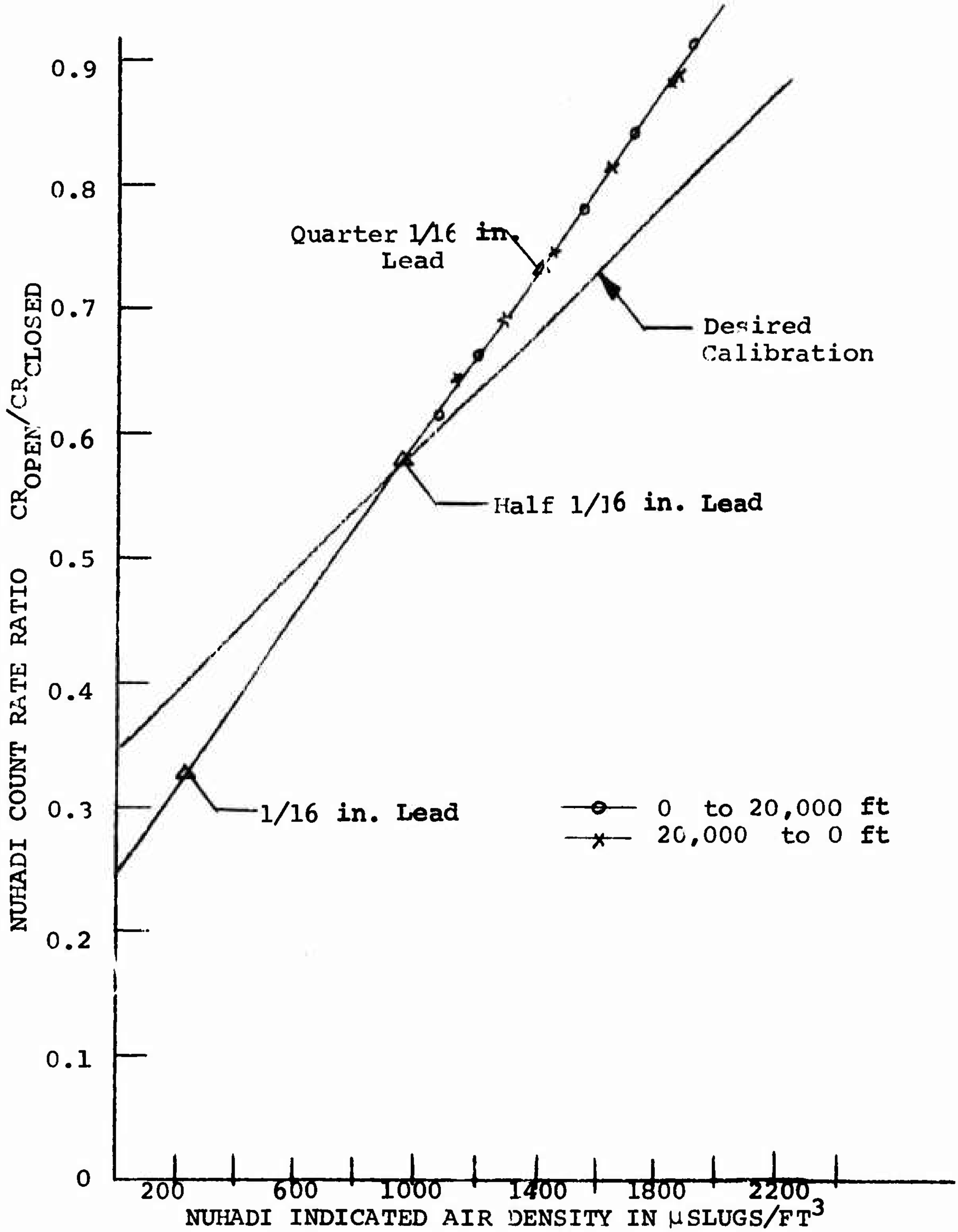

Figure 13. NUHADI Calibration CR Ratio Versus Air Density.

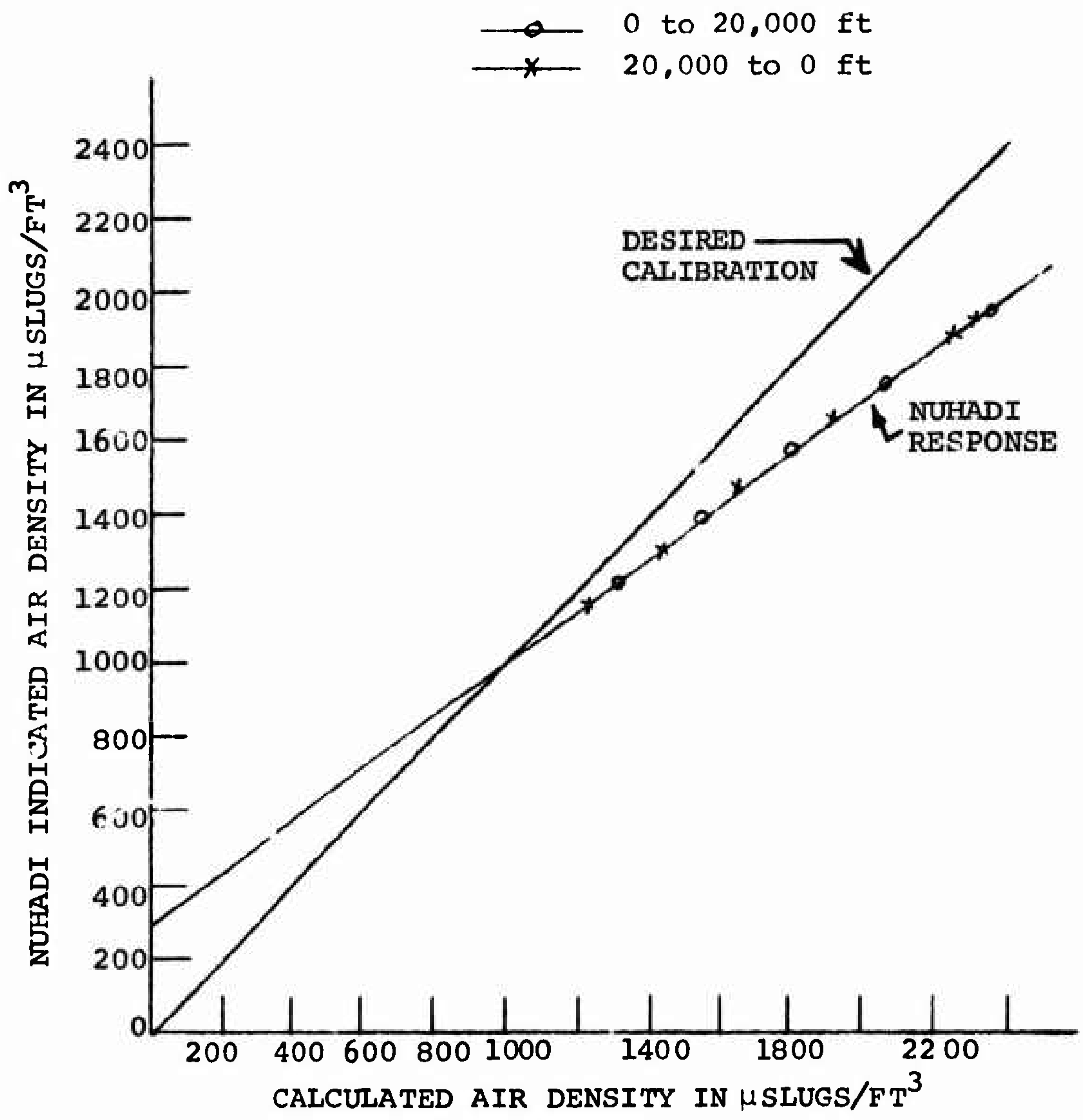

Figure 14. NUHADI Readout Versus Chamber Air Density.

the data. Thus the NUHADI accuracy is estimated to be ± 0.5% or better. Because ten readings were recorded at each altitude and the average of the ten used for calibration, the one sigma statistics were reduced to ± 0.22%. One sigma statistics for individual readings were ± 0.7% of sea level density (± 14μ slugs/ft^3).

FLIGHT TESTS AT FORT EUSTIS

The NUHADI system was installed onboard a UH-1H helicopter and flight tested at Fort Eustis, Virginia during the period of July 16 through July 27, 1973.

Installation

Some modification of the mounting platform was found to be necessary to allow the unit to be mounted as planned. This involved trimming the lower edge and upper corners of the platform, etc., which did not compromise the structural integrity. It was found possible to mount the unit without drilling holes in the bulkheads as had been planned. This was accomplished by using the lightening holes in the two bulkheads. Figures 15 and 16 are photographs showing the NUHADI sensor installed in the tail boom area of the helicopter. In Figure 15, a view looking aft, two of the handmade brackets can be seen in the lightening holes of the bulkhead at station 3843 of the tail boom. In Figure 16, a view looking forward, one of the lightening hole brackets in the 5950 bulkhead is barely visible in the upper left corner of the photograph. Figure 17 is a photograph of the exterior of the helicopter along the port side. The NUHADI sensor looks out of the helicopter skin along the upper bar of the E in UNITED. Just to the right of the D is a radiation warning sign. Just to the left of the junction of the tail boom assembly with the fusalage, the humidity sensor (provided by AMRDL) can be seen. The warning light, which indicates sensor collimator open, can be seen just to the right of the humidity sensor. Figure 18 is a photograph of the cabin of the helicopter. The NUHADI electronics/display unit can be seen tied down in front of the seats. Behind this unit is the recorder, etc., provided by AMRDL for measuring and recording air pressure, temperature, and humidity. The NUHADI power supply unit was placed under the seats and is not visible in the photograph.

Flight Tests

The flight tests of the NUHADI were conducted on July 24, 25 and 26, 1973 at Fort Eustis, Virginia. On the first test flight (July 24), data was taken at 1000 feet intervals from the ground up to 10,000 feet. This was primarily an operation/

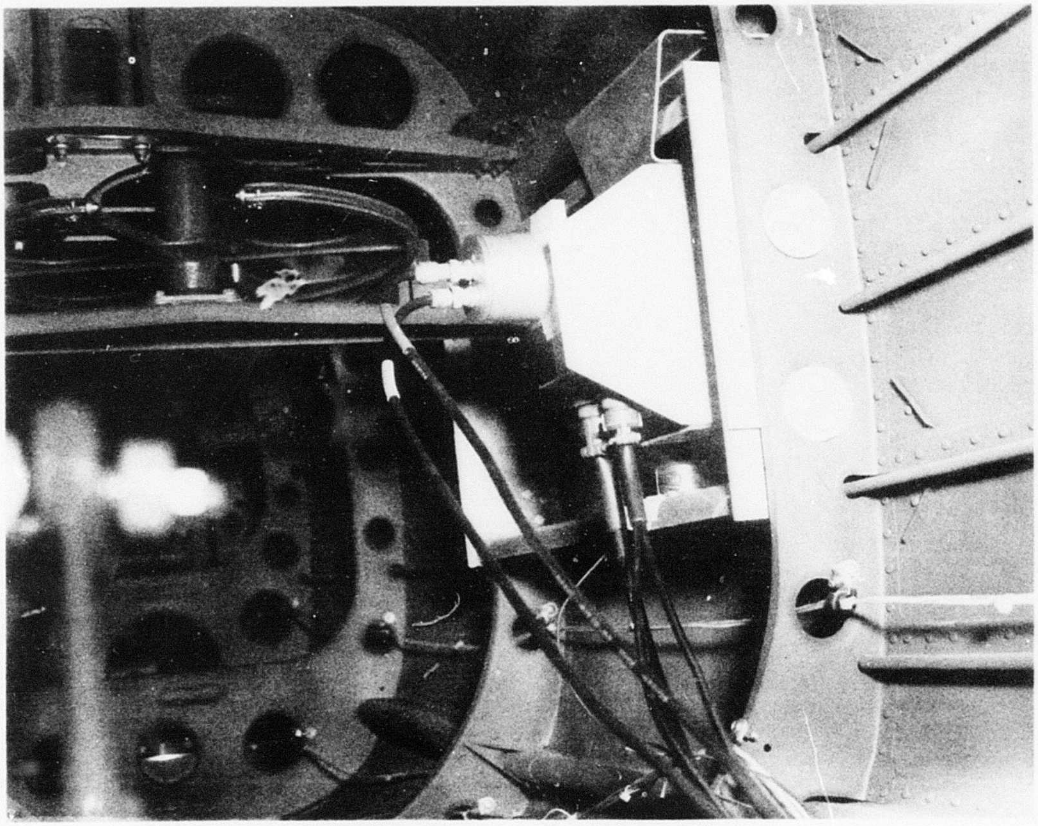

Figure 15. NUHADI Sensor Mounting - Interior View Looking Aft.

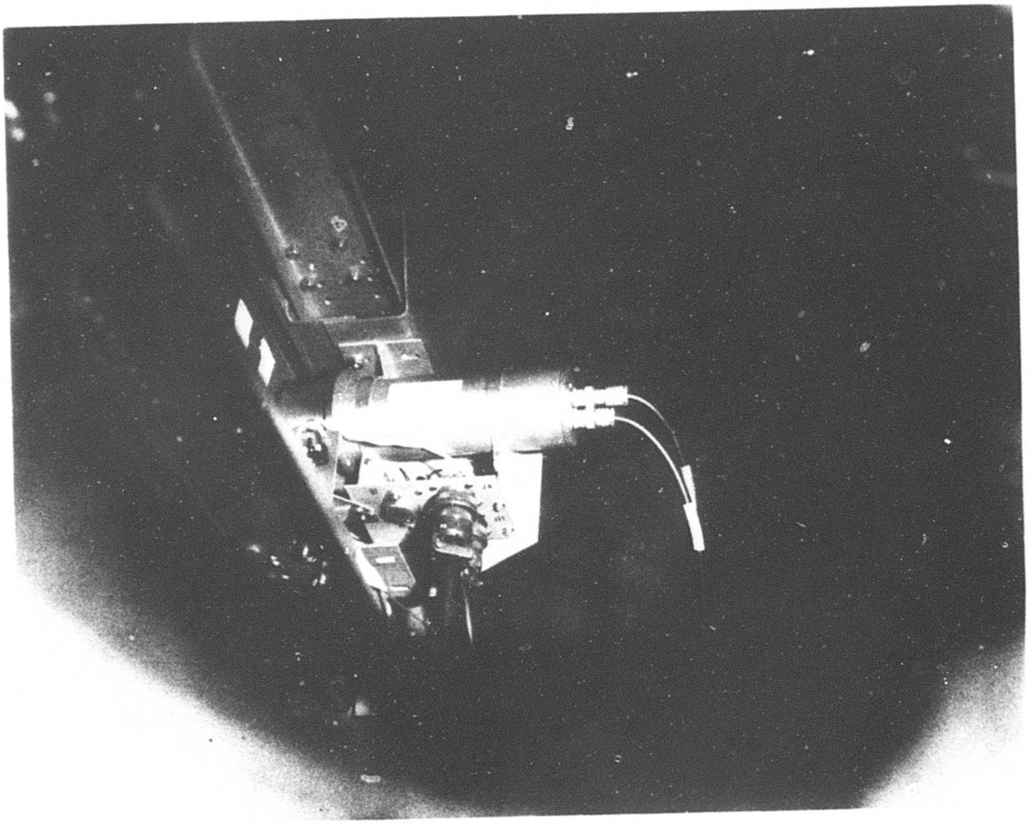

Figure 16. NUHADI Sensor Mounting - Interior View Looking Forward.

Figure 17. NUHADI Installation,
Port Side of Tail Boom.

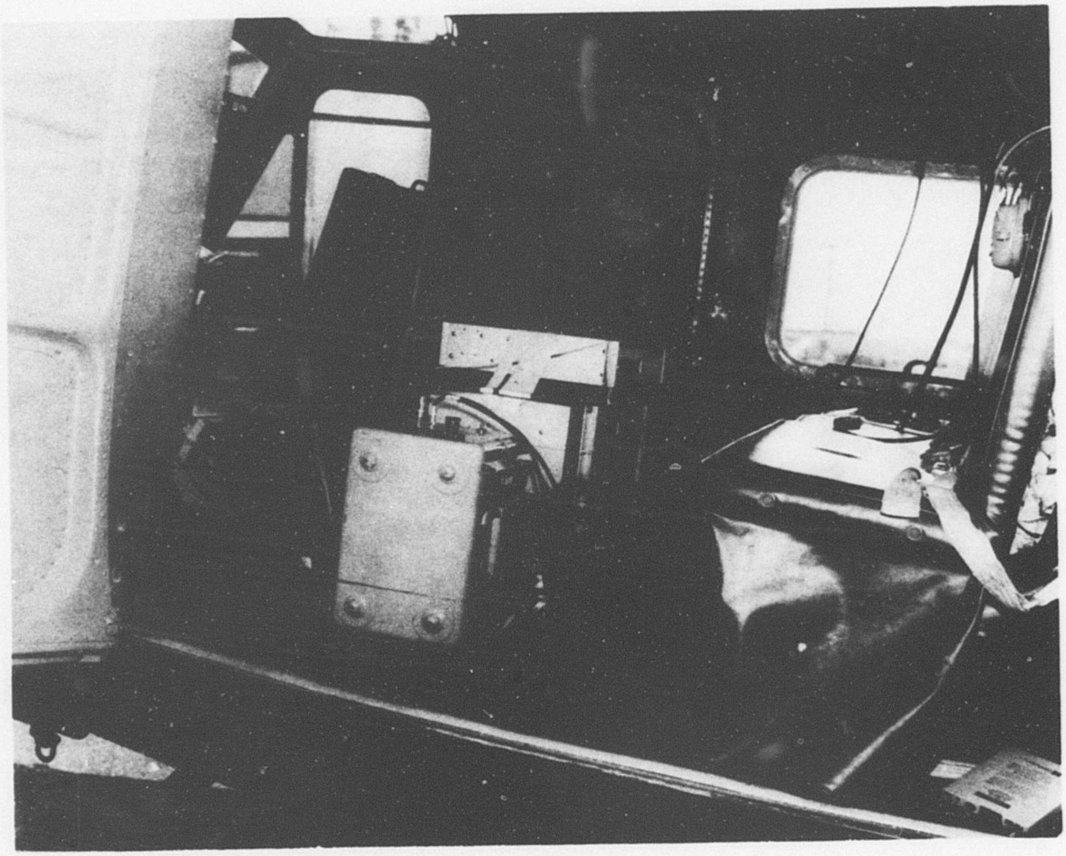

Figure 18. NUHADI Flight Test Installation of Electronics/Display Unit.

calibration run and showed that recalibration was necessary. This flight was also a first check-out run for the AMRDL instrumentation, the pressure, temperature and humidity sensors, and the recording equipment. All systems seemed to operate well; however, some difficulty was encountered in incorporating the humidity data into the air density calculation. Therefore, the NUHADI was only roughly recalibrated prior to the second test flight. On the second test flight (July 25), data was taken at 0, 20 feet hover, 100 feet, 2000 feet, and at 2000-foot increments on up to 14,000 feet. The test plan called for data at the same altitudes on the way back down; however, the system malfunctioned at 12,000 feet (descending), so the helicopter was brought down directly to 1000 feet. The electronics/display unit case was opened at 14,000 feet to take count rate data which caused the malfunction (the cabin was quite cold). Reduction of the data from the flight tests on the 24th and 25th provided the necessary information for recalibration. The NUHADI was recalibrated by setting the low-density adjustment (with the cadmium calibration plate in place) at 200μ slugs/ft^3 and setting the high density adjustment to 100μ slugs/ft^3 higher than the actual calculated ground ambient air density. The third test flight (July 26) was flown to the same flight plan as the second. The data from this flight is presented in the appendix. Figure 19 is a plot of this data, NUHADI readout (indicated air density) plotted against the calculated air density from onboard measured pressure, temperature and humidity. It can be seen that the calibration was still slightly off: approximately 20μ slugs/ft^3 at the high end.

As there was some doubts concerning the calibration of the humidity sensor, flight tests were concluded at this time. The NUHADI readout agreed with calculated air density within the margin of error that could be contributed by erroneous humidity readings[7].

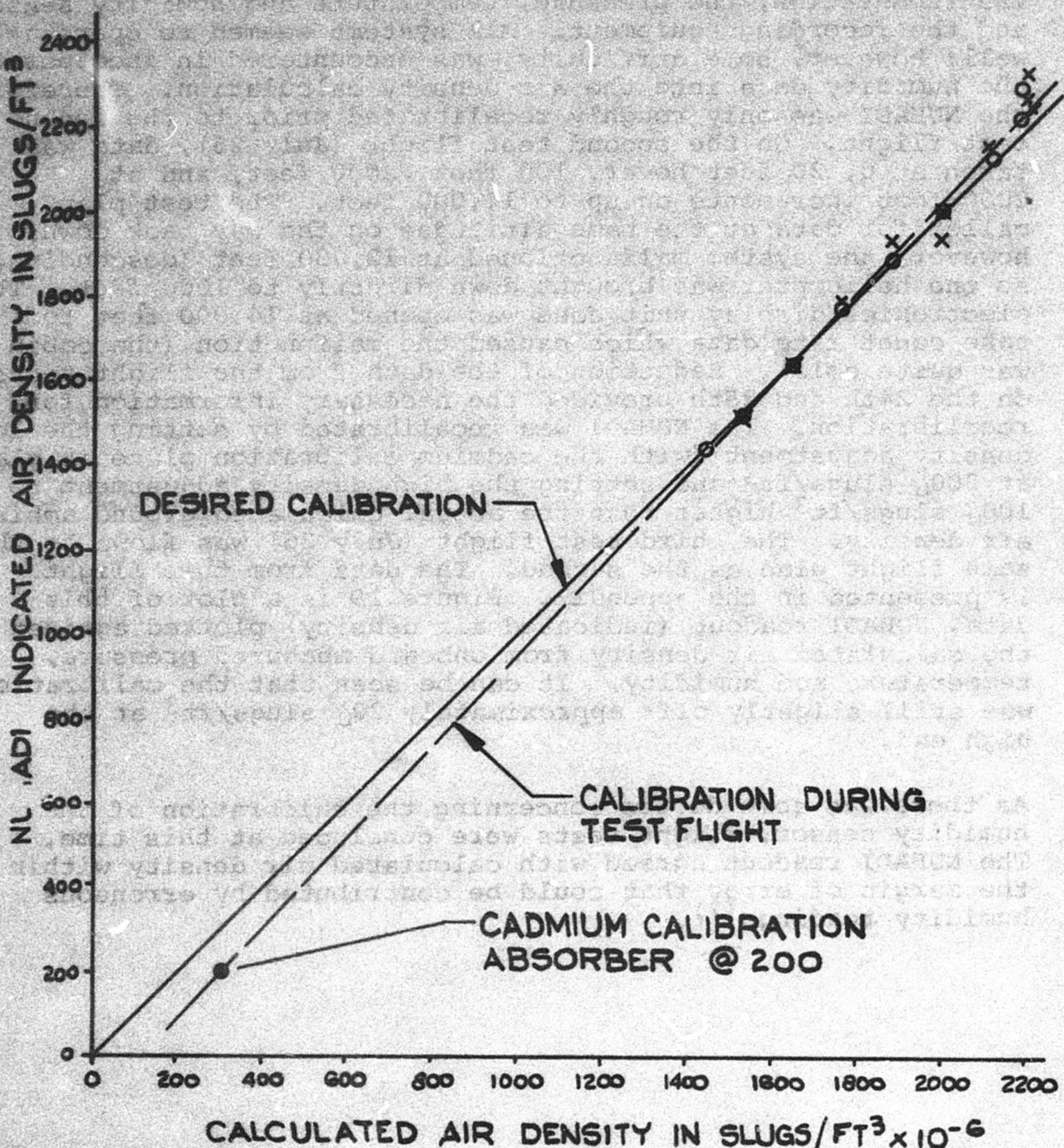

Figure 19. Test Data From July 26 Flight.

RADIATION SAFETY AND HANDLING INFORMATION

GENERAL INFORMATION

It is expected that many people who will be associated with the NUHADI system will not be familiar with radiation, the use of radioactive sources, or the terminology used. While use of the NUHADI does not require any specialized knowledge about radiation and the NUHADI is designed to eliminate any hazards to maintenance and flight personnel, a brief discussion of radiation may be of interest to users of the Gage.

Everyone is exposed to some radiation throughout his life. First, a small part of the cosmic radiation that strikes our atmosphere penetrates the earth's blanket of air to reach the surface. Second, the earth contains naturally occurring radioactive material (uranium ore, potassium-40, etc.) and there are minute quantities of radioactivity in practically all the materials we use and even in our bodies. Third, nearly everyone is exposed to medical or dental X-rays from time to time. The following sections discuss the units used in measuring radiation and the radiation exposure we can expect from radiation in general and the NUHADI in particular.

UNITS USED IN DISCUSSING RADIATION

The Roentgen

Several units are used when discussing radiation dose or radiation dose rate. Historically, the first unit used was the roentgen, named after the discoverer of X-rays, W.K. Roentgen, which is actually a measure of the amount of ionization caused by radiation. One roentgen of X-ray or gamma radiation will cause ionization of one electrostatic* unit of charge in each 0.001293 gms of air (one cubic centimeter of air at 0°C and 760 mm Hg pressure). The roentgen is often abbreviated as R and the milliroentgen as mR (1/1000 of one R). The roentgen is called exposure, or exposure rate when expressed in roentgens per hour (R/hr) or milliroentgens per hour (mR/hr). The roentgen is a very useful unit primarily because it is directly and easily measured.

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*The electrostatic unit of charge, one e.s.u., is equal to 2.083×10^9 ion pairs.

The Rad

The effects on materials from different kinds of radiation are closely related to the energy deposited per unit mass in the material. Because different kinds of radiation deposit more or less energy for the same exposure in roentgens, several other units have come into use. One of the most used units is the rad, which stands for radiation absorbed dose.

ne rad is equal to 100 ergs of energy absorbed in each gram of material (100 ergs/gm) and a millirad (mRad) is 0.1 ergs/gm (also rad/hr and mRad/hr for absorbed dose rate).

The Rem

For living tissue, even the same number of rads of different kinds of radiation are not equivalent, so another unit, the rem for "radiation equivalent man", is used. The rem and rem/hr (also millirem and millirem/hr) are the standard units for radiation protection. With the rem family of units, we can compare the absorbed dose rate of X-rays, cosmic rays, neutrons, etc., knowing that the same quantities will have equivalent effects on the person or persons exposed.

This abundant family of radiation units is confusing - even if necessary. However, when we deal only with X-rays, gamma rays and beta radiation, there is a one-to-one correspondence. Exposure to one roentgen/hr results in one rad/hr to material in the field and one rem/hr to living tissue for all radiation produced by Kr-85.

Relation of Time, Distance, and Dose Rate

Sources of radiation can usually be defined in terms of the dose rate they produce, either in mR/hr, mRad/hr or mRem/hr. For most sources of radiation, the radiation intensity decreases by the square of the distance from the source (the $1/r^2$ law). This is true whenever the distance to the source is much larger than the source dimensions. For instance, a small radioactive source that measures 16 mR/hr exposure dose rate at 1 foot distance will measure 4 mR/hr at 2 feet and only 1 mR/hr at 4 feet.

While dose rate characterises the emission or strength of a source of radiation, it is the absorbed dose that is important to the personnel working with it. The absorbed dose is simply the product of exposure dose rate times the exposure time. A person who remains one hour in a position where the exposure

dose is 10 mR/hr will receive 10 mRem* of dose. If he could reduce his exposure time to 15 minutes, the dose would be only one-fourth as much - 2.5 mRem.

$$10 \text{ mR/hr} \times 1/4 \text{ hr} = 2.5 \text{ milliRem}$$

These two factors should be remembered by all who work near sources of radiation. First, that the exposure dose rate is a function of the distance from the source; second, that the absorbed dose received is a function of the time spent in the radiation field.

The Curie

The curie (named after Madam Curie, the discoverer of Radium) is different from those units discussed above. The curie is a measure of the quantity of radioactive material in terms of the average number of atoms that undergo disintegration every second. One curie** is 3.7×10^{10} disintegrations per second; one millicurie (mCi) 3.7×10^{7} (37,000,000) disintegrations per second. A wrist watch with a luminous dial might contain a few microcuries or less of source while a radioisotope powered battery contains thousands or millions of curies. Yet both are quite safe when properly built and properly used.

RADIATION PROTECTION STANDARD

The U.S. Atomic Energy Commission (AEC) and State regulatory agencies have set limits for occupational radiation exposure to people who work around radiation (and who will therefore wear film badges to measure the absorbed dose they receive) and different limits for individuals of the general public who have no way of knowing how much radiation they might be exposed to.

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*For X-rays, gamma rays and beta radiation.

**Originally defined as one gram of radium or equivalent. In each gram of pure radium-226, approximately 3.7×10^{7} atoms will decay to radon gas each second.

The occupational dose limit for persons over 18 years old* is 5 rem per year or 1.25 rem/calendar quarter whole body dose** and 75 rem/hr or 18.75 rem/calendar quarter to the extremities (hands, forearms, feet and ankles). However, radiation exposure to individuals of the general public must be kept low enough so that no individual can receive more than 0.5 rem/yr whole body dose, 1/10 the amount for the group where the absorbed dose is measured and permanent records kept.

These limits are based on the best available knowledge of "safe" radiation levels; i.e., radiation dose levels well below that where physical damage might occur.

AVERAGE RADIATION EXPOSURE

The average dose from man-caused radiation for persons living in the U.S. is about 1.2 rem/yr, of which 94% is from medical and dental exposure.[5] Also, all people are exposed to terrestial radiation (radiation from the radioactive elements in the earth, in most of the materials around and even some natural occurring radioisotopes, like K-40, in the body) and from cosmic rays. The contributions from each of these depend on the area where one lives. Cosmic ray intensity varies with altitude and somewhat with latitude. Cosmic ray intensity is about 2 1/2 times higher in Denver, Colorado, than in New York City for instance. Also, some areas of the world have more uranium or radioactive potassium in the soil and underlying strata. The average total dose from both terrestial radiation and cosmic rays is about .150 rem/yr[6], but it might be five times that in certain areas of the world.

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*Individuals less than 18 years old are limited to 1/10 these amounts even if they wear film badges.

**Does not include absorbed dose from medical or dental diagnosis or therapy.

RADIATION EXPOSURE FROM THE NUHADI

The NUHADI system uses a sealed source of radioactive Krypton gas (Kr-85) of 2.25 curies strength. This source emits both beta particles and gamma rays. The betas (negative electrons) are completely stopped in the source capsule walls, but they produce X-rays which do emerge from the source. Because the gammas are emitted with only 0.4% abundance (one gamma for every 250 atoms that decay) and X-rays are generated with about 3 or 4% efficiency, the equivalent gamma source strength is less than 80 millicuries.

The NUHADI sensor is shielded so that nearly all the radiation is emitted into a conical-shaped volume extending out from the horizontal center line of the port side of the tail boom at approximately boom station 44.0. The radiation exposure dose rate is less than 2.5 mR/hr at 2 feet from the surface, or at 2 feet from the sensor inside the ship, when the shutter is closed. With the source collimator rotated open, the exposure dose rate outside increases to 16 mR/hr at 2 feet, but it is still less than 2.5 mR/hr at 2 feet inside. Figures 20 through 24 show radiation exposure rate profiles for the NUHADI sensor with the collimator open and collimator closed. Two feet is a resonable average whole body distance for working on or checking the sensor. The hands and arms of the maintenance personnel will be closer, of course, but the body extremeties (hand, arms, feet and legs) are much less susceptible to radiation than are parts of a person's body. The AEC allows 15 times as much absorbed dose, in fact: 18.75 rem/calendar quarter for body extremities compared to 1.25 rem/calendar quarter for the whole body.

RADIOACTIVE CONTAMINATION

The potential hazard of radioactive contamination, that is, the possibility that a source will leak or break open and radioactive material will spread around to eventually be ingested or inhaled, has prevented many otherwise useful isotope systems from achieving their potential. Even when use is allowed, most radioactive sources must be professionally leak tested at 6-month intervals (or more often) to lessen the chance of contamination. Kr-85 sources need not be leak tested because Kr-85 sources cannot contaminate. The reason Kr-85 is so much safer than almost any other source material is because krypton is an inert gas. If a Kr-85 source leaks or is broken open, the radioactive krypton disipates harmlessly into the atmosphere*. Because krypton is inert (like all noble gases,

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*The earth's atmosphere contains millions of curies of Kr-85, but dispersed in the huge volume of air, the effect is barely measurable.

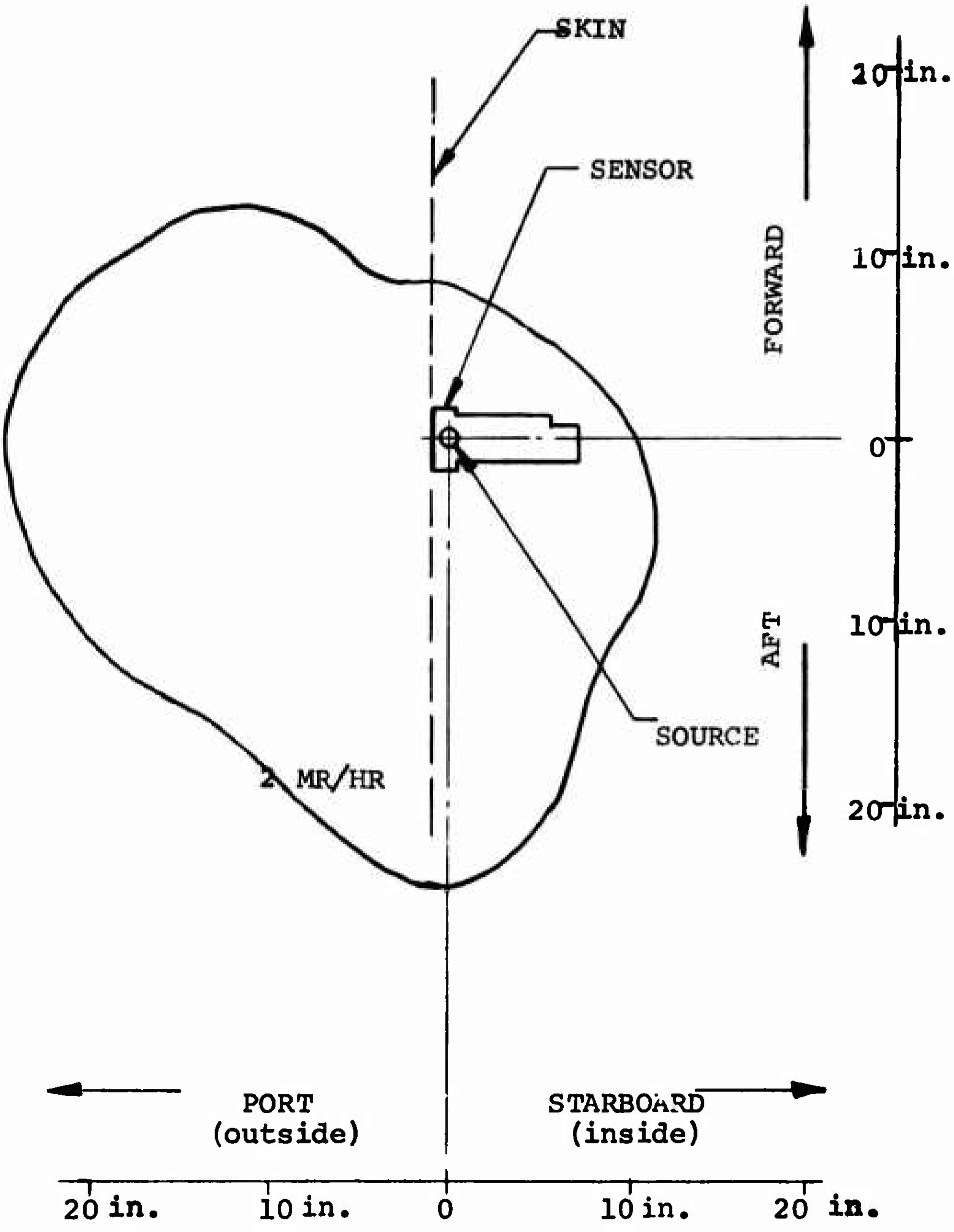

Figure 20. NUHADI 2 $MR/_{HR}$ Dose Rate Profile - Source Closed, Plan View.

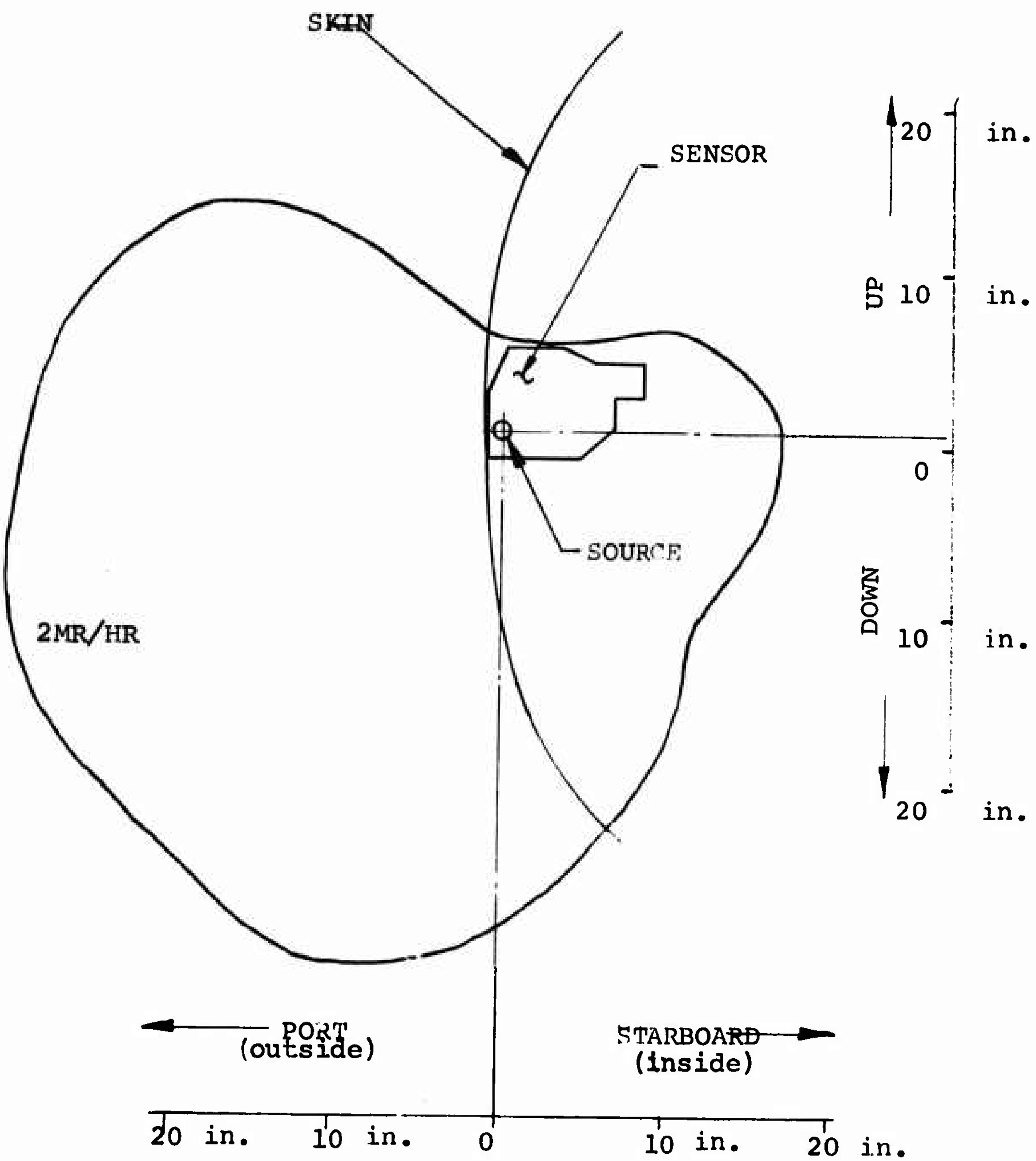

Figure 21. NUHADI 2 MR/HR Dose Rate Profile - Source Closed, Side View.

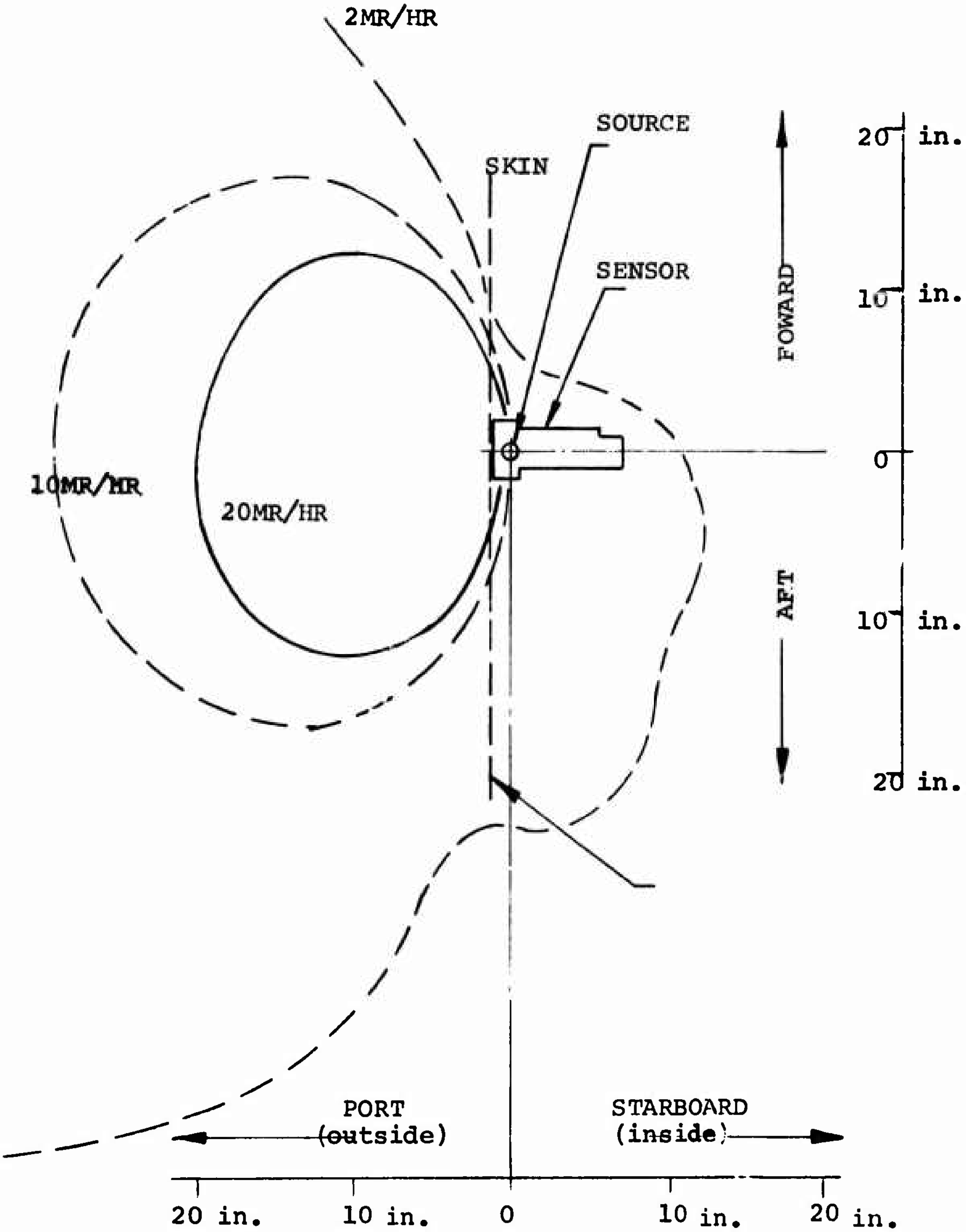

Figure 22. NUHADI Dose Rate Profiles, Source Open Plan View.

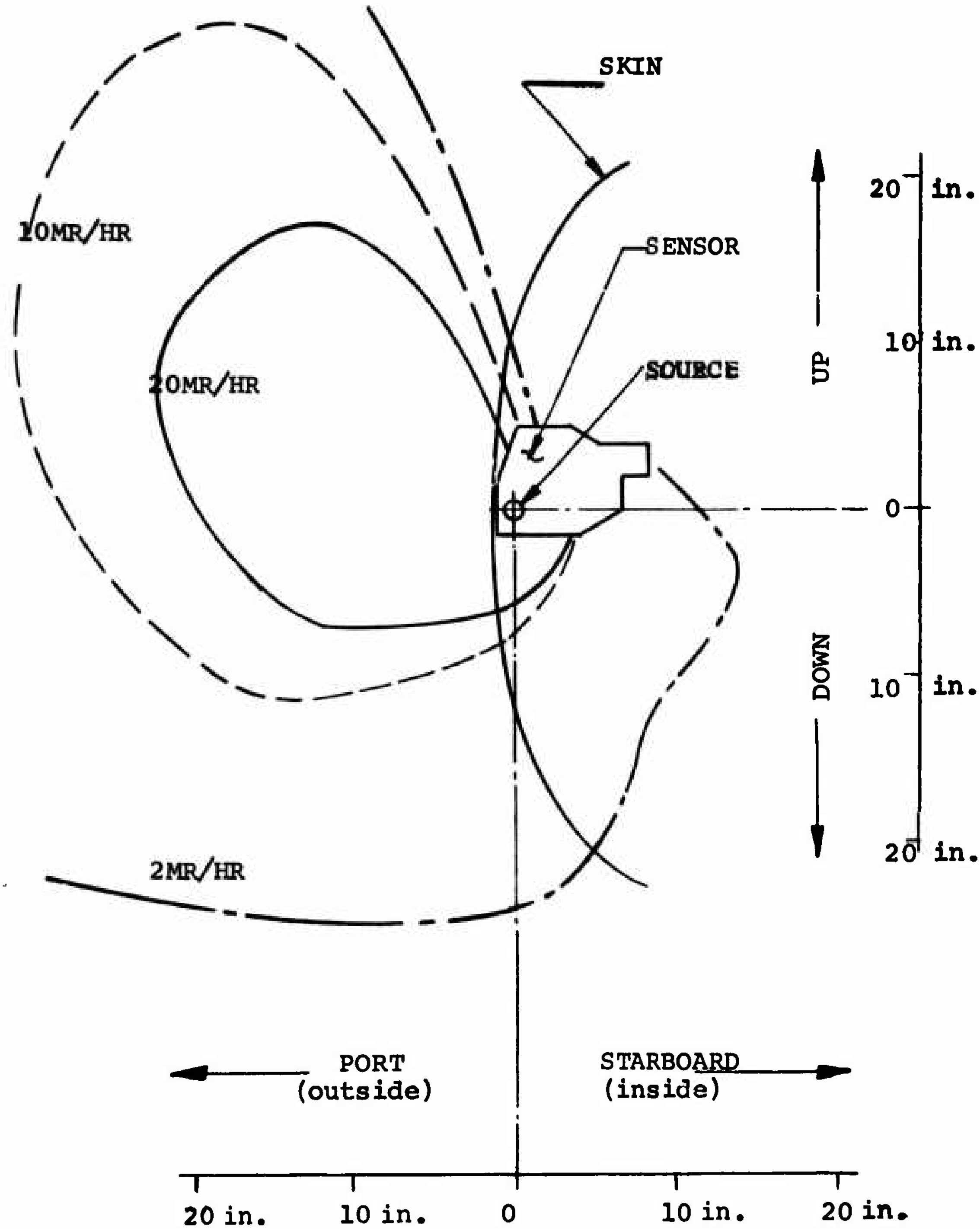

Figure 23. NUHADI Dose Rate Profiles Source Closed - Side View.

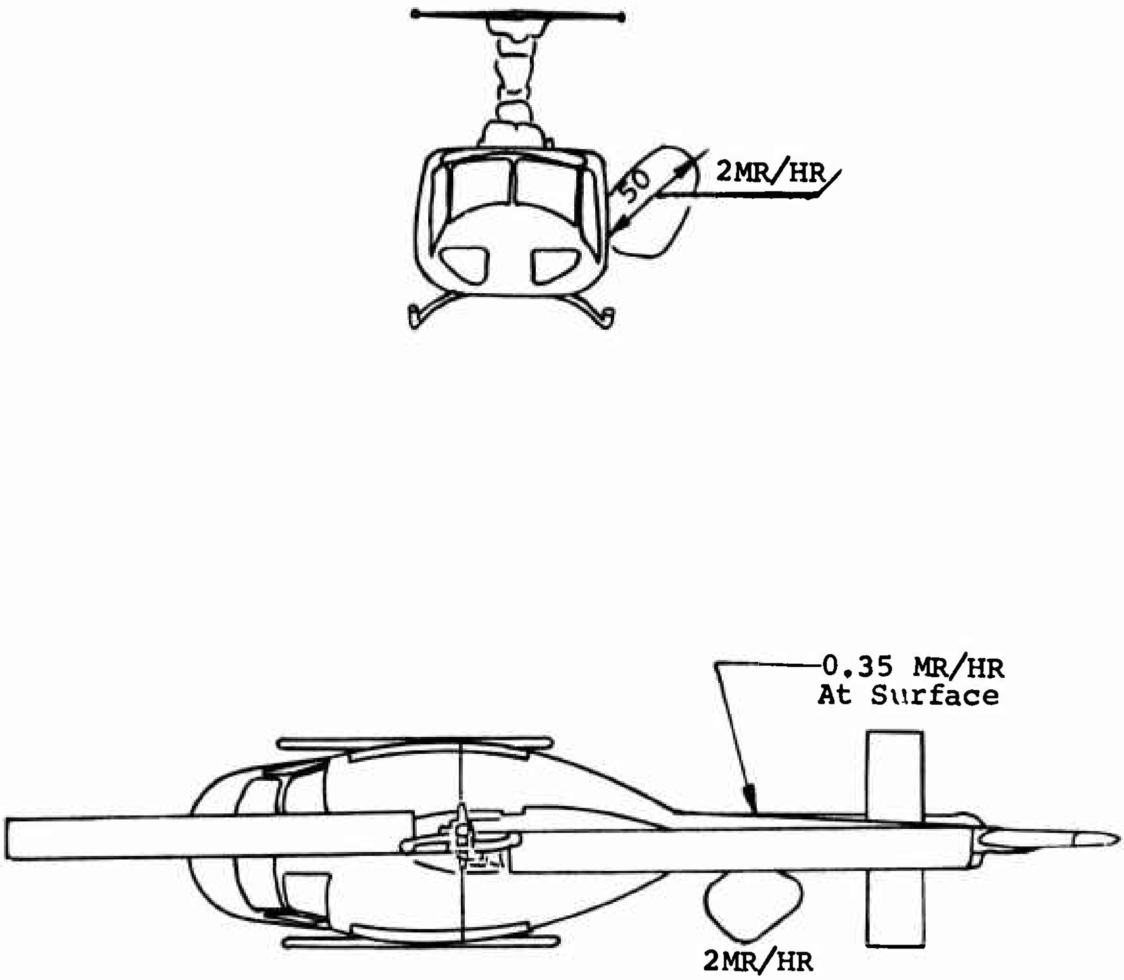

Figure 24. NUHADI Source Open 2 MR/$_{HR}$ Dose Rate Profile Near Helicopter.

krypton does not combine chemically with other elements), it will not be retained by the body even if some is breathed into the lungs. The Air Force of the U.S. and several other nations have used the Nucleonic Oil Gage on several thousand aircraft over the last 7 years. These systems use Kr-85 sources ranging from 0.3 to 3.4 curies per aircraft. Krypton is the only source used for these gages, as the Air Force is concerned with the very real possibility of aircraft crashes and/or fires. Experience has shown that Kr-85 sources do not constitute a hazard - even in the case of source destruction in an aircraft accident.

RADIATION DOSE TO PERSONNEL

In this section, the approximate radiation dose to Army personnel resulting from the NUHADI flight test program is calculated. Although the calculations are based on estimates of the time and proximity for various operations, in all cases the estimates are purposely high so that the results will be a worst case. More man-hours per task and more tasks than are considered necessary are postulated. Also, the shielding of helicopter structure is ignored. The exposure dose rates are based on the measured dose rate profiles shown in Figures 20 through 24. The various groups considered are:

Flight Crew	Ground Handling Crew
Maintenance Personnel	Installation Crew

Flight Crew Personnel

The flight crew personnel are located at various distances from the NUHADI sensor. The closest area is the side facing seats on the port side at approximately 12 feet. The various parts of the cabin are:

Pilot and Co-Pilot	~20 feet
Rear facing seat in cabin	18 feet
Front facing seat in cabin	16 feet
Starboard side facing seats	14 feet
Port side facing seats	12 feet

The exposure dose rate in the direction of the cabin is quite low: less than 2 milliroentgens per hour in either collimator open or collimator closed conditions at less than 1 foot. The dose rate decreases as $1/r^2$ where r is the distance to the NUHADI source. Thus, the exposure dose at the nearest part

of the cabin is:

$$2 \text{ mR/hr} \times \frac{1}{12^2} = 2 \frac{\text{mR/hr}}{144} = 0.014 \text{ mR/hr}$$

Even if flight tests are conducted 8 hrs/day, 5 days/week throughout the calendar quarter, the helicopter crew can receive at most:

$$0.14 \text{ mR/hr} \times 520 \text{ hr} = 7.2 \text{ mRem/calendar quarter}$$

Which is about 1/5 of what they will get from cosmic rays alone during that period.

Ground Handling Crew

We assume that certain personnel will work for short periods around the exterior of the helicopter, refueling, tying down the aircraft or rotor blades, etc., and may be briefly in the cabin. These people will not, however, work inside the tail boom or spend protracted periods near the aircraft. All ground handling personnel should be informed about the NUHADI warning light and should keep at least 10 feet away from the rear, port side of the helicopter whenever the light is on. From the dose rate profiles in Figure 22, the exposure rate at 2.5 ft is ~10 mR/hr maximum. At 10 feet, the exposure rate with collimator open is:

$$10 \text{ mR/hr} \times \frac{2.5^2}{10^2} = 0.625 \text{ mR/hr}$$

The AEC regulations state that the general public (nonoccupational radiation workers who do not wear personnel dosimeters) should not receive more than 2 mRem in any one hour, 100 mRem in any 8 consecutive days, or 0.5 Rem/year*. Let us suppose that one member of the ground handling crew will spend 4 hrs/week, every week of the year, near the exterior of the helicopter where the sensor is located. He will receive:

$$2 \text{ mR/hr} \times 4 \text{ hr/wk} \times 52 \text{ wk/yr} = 216 \text{ mR or } 216 \text{ mRem}$$

This is less than half the allowed yearly dose in what is surely a "worst case". Thus, this group of people will not need to wear film badges or other personnel dosimeters provided that they are forewarned about the warning light and observe the rules.

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*Actually defined as "Permissible Levels of Radiation in Uncontrolled Areas".

Maintenance Personnel

Aircraft maintenance personnel may, of course, spend prolonged periods around or in almost any area of the helicopter. Any maintenance personnel who may work on the tail boom area of the flight test helicopter should be issued a film badge and should be required to wear it whenever working on the vehicle when the sensor is installed. The dose rate profiles in Figures 20 through 24 provide the necessary information for calculating the absorbed dose to be expected from maintenance operations in this area. For instance, if a given job requires 2 hours work in an area where the exposure dose rate is 2 mR/hr, the man will receive 2 mR/hr x 2 hrs = 4 mR or 4 milliRem of absorbed dose*. The maintenance personnel should always check that the NUHADI collimator is closed, i.e., that the warning light is off, before working in the area around the sensor.

Installation and Removal of NUHADI Sensor

Personnel installing, removing or working on the NUHADI sensor will naturally receive the most absorbed dose rate and should always wear film badges while engaged in these operations. The original installation was done by General Nucleonics' personnel who had their own film badges. In addition, GND personnel wore pocket dosimeters (a small integrating ion chamber that can be visually read at any time), and their work provided a "worst case" dose for installation procedures. After the first installation, the NUHADI sensor can be dismounted from the 38.43 and 59.50 bulkheads, disconnected from its cables and removed in less than 20 minutes. Reinstallation will require about 30 minutes and checking out the sensor operation and calibrating (installing and removing the calibration absorber) another 5 minutes near the sensor. The man doing this work will be at or inside the 2 mR/hr line, probably at about 3 or 4 mR/hr, but we will assume 5 mR/hr as a worst case. Thus, the absorbed dose for these operations will be:

Sensor removal - 20 minutes

$$5 \text{ mR/hr} \times \frac{1}{3} \text{ hr} = 1.67 \text{ mR or } \underline{1.67 \text{ mRem}}$$

Sensor reinstallation & calibration - 30 minutes

$$5 \text{ mR/hr} \times \frac{1}{2} \text{ hr} = 2.50 \text{ mR or } \underline{2.50 \text{ mRem}}$$

*Most film badges are only read and reported to the nearest 10 mRem as they are not accurate to better than about ±5 mRem.

As previously discussed in the section on Maintenance Personnel, these absorbed doses are too small to be accurately measured by film badges or pocket dosimeters. Unless the same man does several operations with the NUHADI sensor in the same month, the film badge readings will be mostly zero. In a similar case, the Air Force had their people all wear film badges for installating and working around the GND Nucleonic Oil Gage System (NOGS) when they first put the system in use. The NOGS uses about 1/2 curie of Kr-85 in a completely unshielded source. The dose rate at 2 feet is approximately the same as the NUHADI System. Most of the installations were done at McClellan AFB by the same crew. After 18 months and several hundred installations, it was found that all film badge readings were zero. As a result of this, the Air Force rescinded the order that required personnel working on or around the Nucleonics Oil Gage to wear film badges. However, GND recommends that film badges be used in the first application of any nucleonic system until it is assertained that they are not necessary.

During the first installation of the NUHADI sensor in the Flight Test helicopter (see discussion of NUHADI Flight Tests above) the GND Engineer and the AMRDL technical representative on the program spent several days, approximately 25 hours, working with the NUHADI sensor. Their proximity x time exposure was equivalent to that of a trained installation crew installing NUHADI sensors in 5 or 6 helicopters (because it was the first installation and several fittings, modifications, and calibrations were needed). The dose rates reported on their individual film badges were zero for the AMRDL technical representative and approximately 10 mRem (millirems) (approximately because the film badge was worn on other work earlier in the month) for the GND engineer. Film badges are usually reported to the nearest 10 millirem, so the AMRDL representative received between 0 and 5 mRem dose and the GND engineer between 5 and 15 mRem dose. Ten mRem/month is approximately the dose that most individuals (on the east coast) received from natural background radiation.

CONCLUSIONS

The NUHADI system operated quite well during the flight tests. The system was not calibrated exactly to the calculated air density because the humidity sensor calibration data was not available.

Later, the density calculations were revised (it was found that the first calculation of temperature and pressure from the onboard sensors was in error). The differences between calculated air density and the NUHADI indicated air density are tabulated in the Appendix.

STATISTICAL ERROR

The statistical fluctuation of individual NUHADI readings is determined by the open cycle count rate and the slope of the count rate versus air density curve. If CR_o is the count rate at zero density ($\rho = 0$) and S is the slope of open cycle count rate versus air density then

$$\rho = S(CR - CR_o)$$

is the air density corresponding to count rate CR. The delta in density corresponding to a fluctuation in count rate is

$$\Delta\rho = S\Delta CR$$

and

$$\frac{\Delta\rho}{\rho} = \frac{\Delta CR}{CR - CR_o}$$

The zero density count rate (from the preflight calibration) is

$$CR_o = 3460 \text{ counts/sec}$$

The statistical fluctuation ΔCR is determined by both the open and closed cycles. Since the closed cycle simply empties the register filled during the open cycle, an equal number of counts are accumulated in each cycle. At sea level, the open count rate 8300 counts/sec. The open cycle accumulation time (τ) is 5 seconds. Thus the one sigma statistics are:

$$(\Delta N)_{1\sigma} = \pm (2 x CR \times \tau)^{1/2} = \pm (2x8300x5)^{1/2} = \pm 288 \text{ counts/cycle}$$

$$(\Delta CR)_{1\sigma} = \frac{\Delta N}{\tau} = \pm 57.6 \text{ counts/sec}$$

At 14,000 feet, the open cycle count rate is 6000 counts/sec which gives one sigma statistics of

$$(\Delta N)_{1\sigma} = \pm (2xCRx\tau)^{1/2} = \pm (2x6000x5)^{1/2} = \pm 245 \text{ counts/cycle}$$

$$(\Delta CR)_{1\sigma} = \pm 49 \text{ counts/sec}$$

The density readout fluctuation in percent at sea level is

$$\left(\frac{\Delta\rho}{\rho}\right)_{1\sigma} \times 100\% = \frac{\Delta CR}{CR-CR_o} \times 100\% = \frac{\pm 57.6}{8300-3460} \times 100\% = \pm 1.19\%$$

$$(\Delta\rho)_{1\sigma} = \pm 27 \ \mu\text{slugs/ft}^3.$$

While at 14,000 feet altitude,

$$\left(\frac{\Delta\rho}{\rho}\right)_{1\sigma} \times 100\% = \frac{\Delta CR}{CR-CR_o} \times 100\% = \frac{\pm 49}{8300-3460} \times 100\% = \pm 1.01\%$$

and $(\Delta\rho)_{1\sigma} = \pm 23 \ \mu\text{slugs/ft}^3$.

The average density fluctuations are approximately ± 1.1% over the altitude range.

Analysis of the flight test data agrees well with the calculated statistics. During the third flight, 220 individual readings were recorded in sets of ten readings at each altitude or condition. 146 of the 220 readings were within ± 1% (±23 μslugs/ft^3) of the average for their group of 10 readings. This is 66.4% of the 220 data points; approximately the 68% expected of one sigma statistics. In a stability test run, with the helocopter on the ground, 9 sets of data, each consisting of 31 consecutive readings, were recorded. The one sigma standard deviations ranged from 22 to 27 μslugs/ft^3.

With a better slope of the open cycle count rate versus air density, the statistics would be considerably better. With a zero density count rate of 1000 counts/sec or less (as was achieved in an earlier model of the NUHADI), the one sigma statistics could be approximately ± 17 μslugs/ft^3 or ± .75% at sea level and ± 13 μslugs/ft^3 or ± 0.55% at 14,000 feet.

OTHER ERROR SOURCES

Data was taken at the start of the July 24 and July 26 test flight with rotor stationary and with rotor turning to determine if there was a rotor effect on the NUHADI readout. The data was inconclusive: on the 24th, the readout increased 19μ slugs/ft^3 with start up, and on the 26th, the readout decreased 32μ slugs/ft^3 when the rotor was started.

The NUHADI system showed a definite ground effect: an increase in indicated air density of approximately 75μ slugs/ft^3 when the helicopter was on the ground compared to the readout when hovering a few feet off the ground. Since only the extreme edges of the beam of emitted X-rays were scattered off the ground (see previous section on Flight Tests), the magnetude of the ground effect is quite sensitive to any variations. It is quite possible that any signal changes noted when the rotor was started were actually caused by slight changes in the helicopter attitude or even by the effect of the rotor down-wash on the grass. If so, then when the mounting of the NUHADI is changed to eliminate the ground effect, any variations due to the rotor will also disappear.

TOTAL ERROR

The final column in the Flight Test data presented in the appendix shows the difference between the calculated and NUHADI indicated air densities:

$$\frac{\bar{\rho}_{NUHADI} - \bar{\rho}_{CALC}}{\bar{\rho}_{CALC}}$$

where both $\bar{\rho}_{NUHADI}$ and $\bar{\rho}_{CALC}$ are the average air densities from 10 or more readings at the same altitude. Thus the 1σ statistic for the NUHADI air density is reduced to ± 0.4% or less for this comparison. The helicopter was generally able to stay within ± 50 feet of the desired altitude while readings were taken. The correlation was very good during the ascent to 14,000 feet. As noted earlier, the calibration was approximately 1% too high at sea level. This is quite evident from the data; the NUHADI data is about 1% higher than the calculated air density below 2,000 feet, then shifts gradually to a very close correlation from 8,000 to 14,000 feet. With exact calibration, the correlation would have been within 0.5% during the entire ascent (except on the ground). The data correlation was not nearly as good during the descent part of the flight. From 8,000 feet down, most of the NUHADI readings were about 1.5 to 3.5% higher than the calculated values. An exception was the data at 4,000 feet, with the helicopter hovering, where the NUHADI

data averaged 2% lower than calculated value. As all other data indicated that there was no difference in the data due to air speed, the 4,000-foot hovering data is in question. Several data points could have been erroneously recorded.

The cause of the poorer data correlation during the descent is not known at this time. The NUHADI had shown excellent agreement in the 10-4-72 test in the 41-foot-diameter Langley altitude chamber between the ascending and descending pressure altitudes. The pressure temperature and humidity sensors used for the calculated air densities had been seperately calibrated; but, like the NUHADI system, this was their first test installed on a helicopter. Additional flight test data would be useful to resolve this ambiguity.

RECOMMENDATIONS

Additional flight tests of the NUHADI would give a clearer understanding of the systems capabilities. One useful test would consist of alternating sets of data from two altitudes 4,000 to 6,000 feet apart. For instance, a sequence of NUHADI and calculated air densities at 4,000, 10,000, 4,000, 10,000 and 4,000 feet would determine which, if either, system is affected by the history of the flight program. A second useful goal of any further test flights would be to obtain the maximum temperature and humidity ranges possible (including flight during a rain storm).

The statistical fluctuations of individual NUHADI readings were larger than desired. As shown in the preceding section, the ± 1.1% one sigma statistics would have been ± 0.7% if the open count rate versus density slope had been as good as the prototype system; however, even this is larger than is wanted. In an ideal system, the statistical fluctuations would be no more than ± 0.5% on a three sigma basis. This would require one sigma statistics of ± 0.17%.

The NUHADI spends 50% of the time in a calibration cycle and half the statistical fluctuation is caused by the calibration counts. Calibration every 10 seconds was found not to be necessary, a continuous calibration with a time constant of 5 or 10 minutes would be just as accurate and would reduce statistical fluctuations. This would entail using the counts over the upper window threshold (the Kr-85 peak and the Cs-137 AGC peak) and accumulating them in an additional register. The sensor would then stay open during flight and only close when the system was turned off.

Assuming that this modification was made and that the zero density count rate is 10% of the sea level count rate, this would require an accumulated count per cycle of 4.4×10^5 counts, or 4.4×10^4 counts/sec for a 10 second cycle time. This is 5 times the count rate of the present system and would require a source of 10 to 12 curies of Kr-85. With present shielding, the dose rates would be approximately 5 times those shown in the section on radiation safety. Some additional shielding should be added to reduce the closed collimator exposure dose rates to approximately the values of the present system.

The best compromise might be to use a source of about 5 curies Kr-85 (the maximum licensed and planned for the present NUHADI) in a 2 time constant system. With this scheme, the system would normally operate at a count rate of 22,000 counts/sec (at sea level) and with a 10 second cycle time, which is

the same as the present system. This would yield a three sigma statistical fluctuation of ± 0.7% (± 0.23% one sigma). When the maximum accuracy is needed, a longer time constant of 20 seconds would be actuated to obtain the ± 0.5% three sigma statistics (± 0.17% one sigma).

LITERATURE CITED

1. I. Filosofo, L. Reiffel, C.A. Stone, and L. Voyvodic, "Design and Characteristics of Beta Excited X-Ray Sources" Radioisotopes in the Physical Sciences and Industry, pp, 3-39, Vol. II International Atomic Energy Agency, Vienna (1962)

2. R. Gardener and D. Whitiker, "Design Studies of a Gamma-Ray Scatter Atmospheric Density Gage by a Multivariable Search Method", Nuclear Application, Vol. 6, March (1969).

3. D. Blincow, K. Pearson, and R. Ray, "Nucleonic Fuel Gaging Systems for Spacecraft", Radioisotopes for Aerospace, pp. 132-147, Part 2, Plenum Press, N.Y. (1966)

4. D. Blincow, "Final Report on Gamma Ray Intrusion Detection Equipment", General Nucleonics Division of Tyco Laboratories RADC-TR-69-122, 1969 (Classified)

5. K.Z. Morgan, Director, Health Physics, Oak Ridge National Laboratory, from a paper presented at a Symposium on Radiation Legislation presented by the Radiological Society of America, Chicago, Ill., November - December, 1969.

6. H. Blatz, Introduction to Radiological Health, McGraw Hill, N.Y., N.Y., 1964.

7. F. Jones, Air Density and Helicopter Lift, National Bureau of Standards, Janair Report 721201, Jan. 1973.

A

FLIGHT TEST DATA OF 26 JULY 1973	ALT FT	$\bar{\rho}$ NUHADI $\frac{\text{SLUGS}}{\text{FT}^3}$ (10^6)	N NUHADI	RANGE NUHADI $\frac{\text{SLUGS}}{\text{FT}^3}$ (10^6)	Δ NUHADI	σ NUHADI
ASCENDING TO 14000 FT	GND	2308.7	10	2210-2353	.143	43.6
	20	2234.3	10	2187-2273	86	29.2
	100	2239.4	10	2190-2281	91	24.7
	2K	2143.9	10	2121-2184	63	22.0
	4K	2021.5	10	1985-2054	69	24.8
	6K	1900.0	10	1862-1978	116	35.8
	8K	1763.2	11	1723-1832	109	29.3
	10K	1642.5	10	1591.1687	96	27.4
	12K	1540.6	10	1519-1563	44	15.1
	14K	1443.6	20	1394-1492	98	28.4
DESCENDING FROM 14000 FT	12K	1529.9	10	1509-1552	43	14.3
	10K	1655.6	10	1615-1706	91	24.9
	8K	1792.0	10	1733-1845	112	34.8
	6K	1952.8	10	1918-1980	62	18.3
	4K (H)	1957.5	10	1865-2086	251	79.4
	4K (FF)	2034.4	10	2005-2070	65	19.3
	2K	2173.6	10	2159-2202	43	14.9
	100	2293.8	10	2253-2338	85	27.2
	20	2261.0	10	2236-2299	63	18.3
	GND	2348.3	10	2328-2396	68	20.0

B

APPENDIX

DATA FROM NUHADI FLIGHT TESTS

RANGE NUHADI SLUGS/FT³ (10^6)	Δ NUHADI	σ NUHADI	$\bar{\rho}$ CALC SLUGS/FT³ (10^6)	N CALC	RANGE CALC SLUGS/FT³ (10^6)	Δ CALC
210-2353	.143	43.6	2196.9	3	2196-2198	2
187-2273	86	29.2	2211.0	10	2206-2218	12
190-2281	91	24.7	2205.9	12	2189-2219	30
121-2184	63	22.0	2126.0	11	2123-2129	6
85-2054	69	24.8	2012.9	11	2010-2015	5
62-1978	116	35.8	1890.1	11	1888-1895	7
23-1832	109	29.3	1761.8	15	1758-1766	8
91.1687	96	27.4	1648.5	10	1646-1651	5
19-1563	44	15.1	1544.2	13	1541-1549	8
94-1492	98	28.4	1441.6	23	1439-1444	5
09-1552	43	14.3	1544.8	11	1543-1547	4
15-1706	91	24.9	1653.1	13	1651-1656	5
33-1845	112	34.8	1763.8	12	1762-1765	3
18-1980	62	18.3	1884.4	12	1880-1892	12
65-2086	251	79.4	2001.0	16	1990-2016	26
05-2070	65	19.3	2008.7	17	2002-2024	22
59-2202	43	14.9	2117.9	13	2111-2126	15
53-2338	85	27.2	2215.5	14	2210-2221	11
36-2299	63	18.3	2223.5	10	2219-2227	8
28-2396	68	20.0	2214.9	13	2207-2219	12

C

Δ_{CALC}	σ_{CALC}	$\bar{P}$ " Hg	$\bar{t}$ °C	$\overline{RH}$ %	$\frac{\bar{P}_{NUHADI}-\bar{P}_{CALC}}{\bar{P}_{CALC}}$ %	ALT FT
2	0.84	29.813	34.717	43.267	+ 5.09	GND
12	4.61	29.867	33.492	43.592	+ 1.05	20
30	9.60	29.722	32.747	44.373	+ 1.52	100
6	2.29	27.803	23.932	63.505	+ 0.84	2K
5	1.58	25.795	18.097	78.647	+ 0.43	4K
7	2.28	23.925	14.852	76.891	+ 0.52	6K
8	3.30	22.115	13.082	49.288	+ 0.08	8K
5	1.67	20.454	10.019	45.812	- 0.36	10K
8	2.25	18.922	6.438	57.314	- 0.23	12K
5	1.15	17.438	3.088	47.603	+ 0.14	14K
4	1.16	18.914	6.125	62.691	- 0.96	12K
5	1.66	20.445	9.120	47.902	+ 0.15	10K
3	1.34	22.100	12.562	51.943	+ 1.60	8K
12	3.76	23.861	14.988	74.710	+ 3.63	6K
26	7.61	25.636	18.059	74.680	- 2.17	4K(H)
22	6.24	25.795	18.700	76.767	+ 1.28	4K(FF)
15	4.70	27.736	24.094	69.791	+ 2.63	2K
11	3.13	29.700	30.916	54.489	+ 3.53	100
8	3.31	29.783	30.759	52.984	+ 1.69	20
12	3.89	29.848	32.375	52.452	+ 6.02	GND

LIST OF SYMBOLS AND ABBREVIATIONS

A	Amperes
AGC	Automatic gain control
Cs-137	Radioactive isotope of cesium with mass number of 137
E_{max}	Maximum energy of emission spectrum
F/F	Flip-flop
Hz	Hertz or cycles per second
KeV	Kilo electron volts
Kr-85	Radioactive isotope of krypton with mass number of 85
mR/hr	Milliroentgens per hour
MSB	Most significant bit
O/S	One shot
PMT	Photomultiplier tube
PPS	Pulses per second
RC=t	Time constant for resistive-capacitance circuit
Rem	Radiation equivalent man
U	Uranium
V	Volts
$\sim$	Approximately
σ	(Sigma)
μ	Micro (10^{-6})
τ	Tau
ρ	Rho
Δ	Delta
λ	Lambda